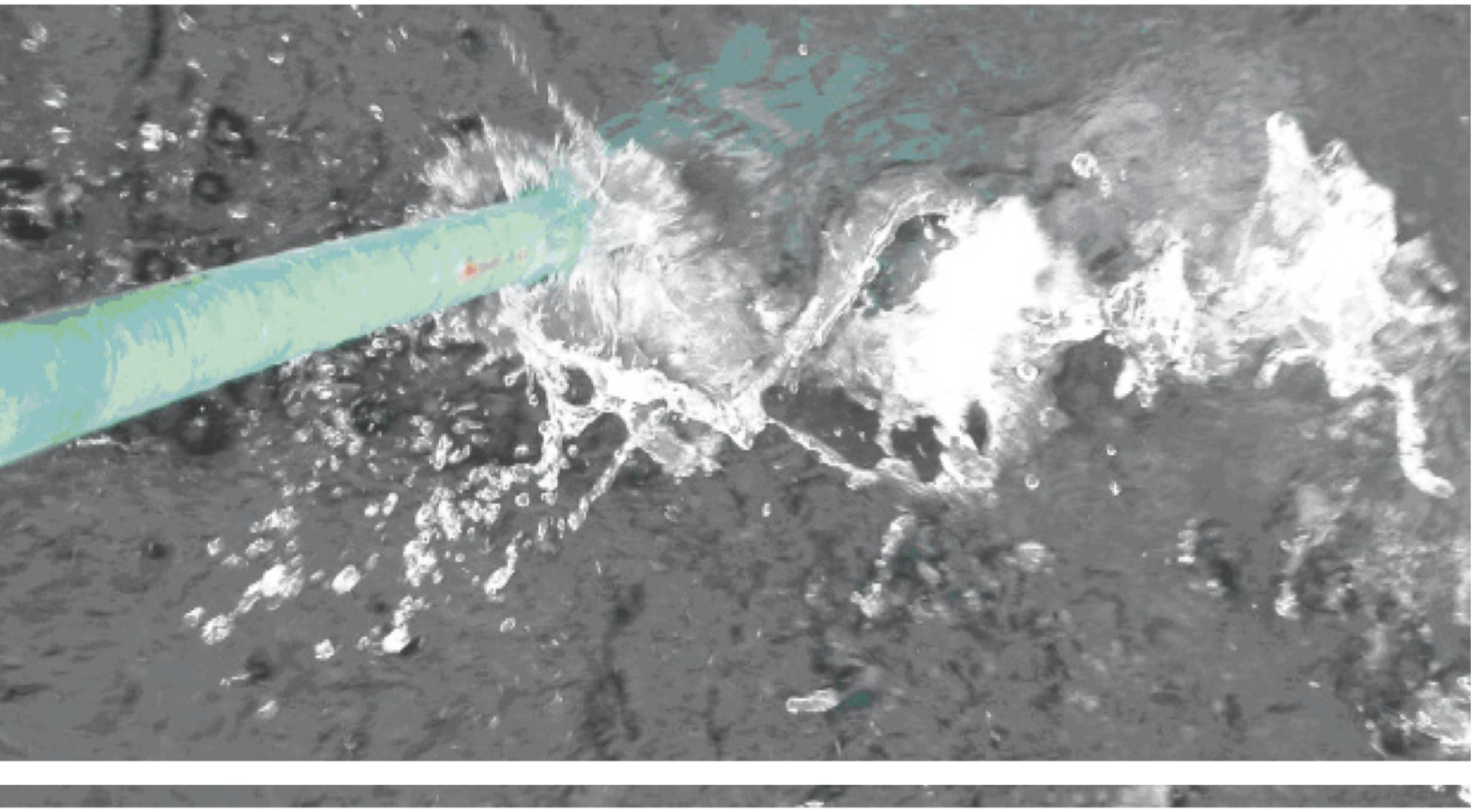
# shear7

## User Guide for SHEAR7 Version 5.0b – *Rev 0*



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## TABLE OF CONTENTS


**1 SUMMARY OF NEW FEATURES IN VERSION 5.0 ..... 1**
1.1 NEW IN VERSION 5.0B ..... 1
1.1.1 Bug Fixes ..... 1
1.1.2 Other Improvements ..... 1
1.2 NEW IN VERSION 5.0A ..... 1
1.2.1 Theoretical Improvements ..... 1
1.2.2 New Strakes With Marine Growth Lift Curves ..... 2
1.2.3 Bug Fixes ..... 3
1.2.4 Licensing Changes ..... 3
**2 SUMMARY OF NEW FEATURES IN PREVIOUS VERSIONS ..... 4**
2.1 NEW IN VERSION 4.12C ..... 4
2.1.1 Improvements ..... 4
2.2 NEW IN VERSION 4.12B ..... 4
2.2.1 Theoretical Improvements ..... 4
2.2.2 Other Improvements ..... 4
2.2.3 Bug Fixes ..... 4
2.3 NEW IN VERSION 4.12A ..... 5
2.3.1 Theoretical Improvements ..... 5
*2.3.1.1 High Reynold's Number Lift Table ..... 5*
*2.3.1.2 Swap The Order That Power Zone Amplitude Limit (PZAL) And Power Cutoff Are Applied ..... 5*
2.3.2 Other Improvements ..... 5
2.3.3 Bug Fixes ..... 5
**3 PROGRAM GENERAL DESCRIPTION ..... 7**
3.1 PROGRAM CAPABILITIES ..... 7
3.2 SHEAR7 ACADEMIC LICENSE ..... 7
3.3 VIV SOLUTION METHOD ..... 8
3.4 VERY LONG CYLINDER MODELING ..... 8
3.5 COORDINATE SYSTEM AND CURRENT PROFILE SPECIFICATION ..... 8
**4 INSTALLATION ..... 10**
4.1 SILENT MODE INSTALL/UNINSTALL ..... 10
4.2 64 BIT EXECUTABLE ..... 11
4.3 REGRESSION TESTS ..... 11
4.4 UNINSTALLING ..... 11
**5 SPECIFICATION OF INPUT DATA ..... 12**
5.1 VERSION CONTROL ..... 14
5.2 BLOCK 1 – UNIT SYSTEM ..... 14
5.3 BLOCK 2 – STRUCTURAL AND HYDRODYNAMIC DATA ..... 16
5.3.1 Flag For The Structural Model ..... 16
5.3.2 Total Length Of The Structure ..... 18
5.3.3 Number Of Spatial Segments (NS) ..... 18
5.3.4 Fluid Density ..... 18
5.3.5 Kinematic Viscosity Of The Fluid ..... 18
5.3.6 Structural Damping Ratio ..... 18
5.3.7 Effective Tension At Origin ..... 19
5.3.8 Number Of Sectional Zones ..... 19

5.3.9 Zone Structural And Hydrodynamic Properties....19
*5.3.9.1 Zone Start And End Point In X/L....19*
*5.3.9.2 Hydrodynamic, Strength Outer And Inner Diameters....21*
*5.3.9.3 Inertia, Mass, Submerged Weight....23*
*5.3.9.4 Modulus Of Elasticity And S-N Curve Identification Number....25*
*5.3.9.5 Reduced Velocity Bandwidth, Strouhal Number, Lift Coefficient Reduction Factor, Zone CL Type ....25*
*5.3.9.6 Added Mass Coefficients And Hydrodynamic Damping Coefficients....30*
*5.3.9.7 Multiple Zones....31*
5.4 BLOCK 3 – SPECIFICATION OF CURRENT PROFILES.... .32
5.4.1 Current Data – Line 1....32
5.4.2 Current Profile Data – Line 2 Through End Of The Current Profile....32
5.5 BLOCK 4 – S-N CURVE AND SCF DATA.... .37
5.5.1 Number Of S-N Curves....37
5.5.2 S-N Curve Identification And Number Of S-N Curve Segments....37
5.5.3 Cutoff Stress Range....37
5.5.4 Stress Range And Cycles To Failure....37
5.5.5 Global Stress Concentration Factor....38
*5.5.5.1 Bending Stress Curvature Load Factor....38*
5.5.6 Number Of Local Stress Concentration Factors....39
*5.5.6.1 X/L Location And Local Stress Concentration Factor....39*
5.6 BLOCK 5 – COMPUTATION/OUTPUT OPTIONS.... .40
5.6.1 Calculation Option....40
*5.6.1.1 Required Inputs For The Available Calculation Options....41*
5.6.2 Locations For Output Summary....42
5.6.3 Acceleration Of Gravity (for Tilt Contamination Estimation)....43
5.6.4 Power Ratio Cutoff Level And Primary Zone Amplitude Limit....43
*5.6.4.1 Power Ratio Cutoff Level....43*
*5.6.4.2 Primary Zone Amplitude Limit (PZAL)....44*
5.6.5 Power Ratio Exponent....46
5.6.6 Higher Harmonics Correction Amplification Factor And Threshold.... .47
5.6.7 Traveling Wave Excitation Ratio....47
5.6.8 Beta Iterations Control Number....48
5.6.9 Fatigue Calculation Diameter Flag....49
5.6.10 Reference Diameter For A* Calculation....49
5.6.11 Import Common.s7cat....49
*5.6.11.1 Common.s7cat Specification....50*
5.6.12 Flag For MATLAB Animation File....50
5.6.13 Flag For .s7log File....51
5.6.14 Flag For .s7dmg File....51
5.6.15 Flag For .s7fat File....51
5.6.16 Flag For .s7out Or .s7out1 And .s7out2 Files....51
5.6.17 Flag For Zero Crossing Frequency Fatigue Calculation....52
5.6.18 Flag For Pure In-line Fatigue Calculation....52
5.6.19 Flag For .s7str File....52
5.6.20 Flag For Non-Orthogonal Damping....53
5.6.21 Flag For Uniquely Named Lift Table File....53
5.6.22 Flag For Stick-Slip Hysteresis....53
5.6.23 Flag For Generating *.s7curv File....54

5.6.24 Flag For Generating *.s7zeta-hyst File....54
5.7 BLOCK 6 – SUPPLEMENTAL DATA....55
5.8 BLOCK 7 – TIME HISTORY DATA....56
**6 PROGRAM OPERATION AND EXECUTION....58**
6.1 PROGRAM EXECUTION OPTIONS....58
6.2 32 AND 64 BIT SHEAR7....58
6.3 INPUT FILES....58
6.4 COMMAND-LINE OPTIONS....59
**7 AVAILABLE OUTPUT FILES....60**
7.1 ROOT-NAME.S7OUT (ALWAYS CREATED)....60
7.2 ROOT-NAME.S7PLT (ALWAYS CREATED)....72
7.3 ROOT-NAME.S7MDS....73
7.3.1 Common.s7mds Files For Option 2 Or Any .mds File For Option 3:....76
7.4 ROOT-NAME.S7ANM....77
7.5 ROOT-NAME.S7LOG....77
7.6 ROOT-NAME.S7DMG....80
7.7 ROOT-NAME.S7FAT....82
7.8 ROOT-NAME.S7OUT1....83
7.9 ROOT-NAME.S7OUT2....85
7.10 ROOT-NAME.S7STR AND .S7CURV....87
7.11 ROOT-NAME.S7STH AND .S7DTH AND .S7CTH....89
**8 .S7DAT FILE CONVERSION PROGRAM....90**
**9 AVAILABLE EXAMPLES....91**
**10 MODELING GUIDANCE....99**
**APPENDIX A DEFAULT SHEAR7 PARAMETERS**
**APPENDIX B UNDERSTANDING LIFT COEFFICIENT**
**APPENDIX C SHEAR7 ERROR MESSAGES**
**APPENDIX D TUTORIAL / EXAMPLE**
**APPENDIX E VIV TECHNICAL REFERENCES**
**APPENDIX F EXCERPT OF VERSION 4.8 AXIAL FLOW DAMPING TERMS**
**APPENDIX G IN-LINE VIV MODELING USING SHEAR7**
**APPENDIX H UNDERSTANDING $A^*$, $C^*$ AND $U_F$**
**APPENDIX I VARYING STRUCTURAL DAMPING "STICK-SLIP" BETA TEST MODULE**
**APPENDIX J LONGITUDINALLY GROOVED SUPPRESSION (LGS®) TECHNOLOGY**
**APPENDIX K OPTIONAL STRESS TIME HISTORY OUTPUT**
**APPENDIX L TRAVELING WAVE EXCITATION**

## LIST OF TABLES

Table 1: Input Data Units....15
Table 2: SHEAR7 – Structure Models Available....17
Table 3: Example Of Inertia, Mass And Submerged Weight....24
Table 4: Example Of SHEAR7 Input Line For Inertia, Mass And Submerged Weight....24
Table 5: CL Curves Available....28
Table 6: Multiple Zone Example....31
Table 7: Current Definition – Example 1....33
Table 8: Current Definition – Example 1 (x/L Convention Reversed)....34
Table 9: Current Definition – Example 2....34
Table 10: Current Definition – Example 3....35
Table 11: Current Definition – Example 4....36
Table 12: Local SCF Example....39
Table 13: Block 5....40
Table 14: Required Inputs In Block 2 For Calculation Options 2 And 3....42
Table 15: Common.s7cat Example....50
Table 16: Stick-Slip Hysteresis Flag Examples....54
Table 17: Supplemental Data Example....55
Table 18: Block 7....56
Table 19: Command-Line Options....59
Table 20: PLT Columns....72
Table 21: .s7mds Example –Even Nodal Spacing....73
Table 22: S7MDS Block 3 Column Units....74
Table 23: .s7mds Example – Uneven Nodal Spacing....75
Table 24: .s7log Example – Segment Allocations Into Zones....78
Table 25: .s7log Preliminary Calculation Example....79
Table 26: .s7log Final Calculation Example....79
Table 27: .s7dmg Example 1....80
Table 28: .s7dmg Example 2....81
Table 29: .s7fat Columns....82
Table 30: .s7out1 Example....84
Table 31: .s7out2 Columns....85
Table 32: .s7out2 Example....86
Table 33: .s7str Example 1....87
Table 34: .s7str Example 2....88
Table 35: .s7sth Example 1....89
Table 36: Basic Modeling Examples....92
Table 37: Riser System Examples....93
Table 38: Varying Structural Damping “Stick-Slip” Examples....94
Table 39: Time Sharing Function Examples....95
Table 40: Strake Modeling Examples....96
Table 41: Selected Benchmark Risers Examples....96
Table 42: Jumper VIV Modeling Examples....97
Table 43: SHEAR7 Parameters Used For Jumper Examples....98

## LIST OF FIGURES

Figure 1: SHEAR7 Coordinate System....9
Figure 2: Example Of Zone Start And End Point In X/L....19
Figure 3: Example 1 Of Correct Segment Allocation....20
Figure 4: Example 2 Of Incorrect Segment Allocation....21
Figure 5: Example Of Diameters In A Riser With Buoyancy Module Sections....22
Figure 6: Example Of Diameter In A Riser With Insulation Section....23
Figure 7: Example Of Structure Natural Frequencies....26
Figure 8: Possible Excitation Zones....45
Figure 9: Results Of The Mode Interaction Analysis As Reported In The .s7out File....46

# 1 SUMMARY OF NEW FEATURES IN VERSION 5.0

## 1.1 NEW IN VERSION 5.0B

### 1.1.1 Bug Fixes

- Fixed an issue causing non-deterministic behavior for traveling wave excitation in the varying structural damping “stick-slip” module.

### 1.1.2 Other Improvements

- Updated example files with new default parameters

## 1.2 NEW IN VERSION 5.0A

### 1.2.1 Theoretical Improvements

SHEAR7 v5.0a implements the option of a traveling wave excitation scheme which changes the way VIV (vortex induced vibration) response prediction is carried out. This change has been implemented to better align with the observed physics.

SHEAR7 v4.12c and prior versions assume that VIV excitation is entirely standing wave based (i.e. the lift force distribution inside the power in region looks like a standing wave.) This has proven effective for many applications, but field and experimental observations from long flexible structures have shown that real VIV responses often contain significant traveling wave behavior both in the power-out regions as well as inside the power-in regions. This is particularly true in sheared currents where hydrodynamic damping levels vary significantly along the structure. See Section *5.6.7 - Traveling Wave Excitation Ratio* and *Appendix L - Traveling Wave Excitation* for more information.

In most cases, the user should:

- **See similar maximum** predicted response (in both amplitude and stress) values between v5.0a and older versions (v4.12c), and;
- note **different distributions** of response amplitude along the structure (i.e. the location along the riser/cable where the maximum occurs may change).

As part of this change, the input parameter *traveling wave excitation ratio* has been added to Block 5 of the *.s7dat* file. This ratio indicates the contribution of traveling wave excitation to the final modal response results, with the remainder contributed by the existing standing wave excitation calculation. The default value for this is 0.5, but can be set to 0 to replicate the results of v4.12c. If a traveling wave excitation ratio greater than 0.0 is used, non-orthogonal damping should be enabled (Section 5.6.20) and the beta control number (Section 5.6.8) should be set to a non-zero value.

Additionally the following output files have been structurally updated to include some of the final and intermediate results of traveling wave excitation:

- .s7out
  - Adds separate standing wave excitation and traveling wave excitation intermediate results, including modal force magnitude, phase, damping, and power. If the traveling wave excitation ratio is set to zero (0), then traveling wave excitation calculation will not be run and results will be reported as '*'. Note that modal force is now reported with a magnitude and phase for both excitations.
- .s7sth, .s7dth, .s7cth
  - Each mode/frequency segment now contains a section of traveling wave excitation results, followed by a section of standing wave excitation results. The allocation length of these sections for each plotted mode/frequency is dictated by the input traveling wave excitation ratio.
- .s7fat
  - Expansion of the singular modal force column to separate modal force magnitude and modal force phase columns, as well as addition of a new Wave Excitation column to indicate which excitation model the particular results are from. Standing wave excitation rows are marked 0; traveling wave excitation rows, which are omitted when the traveling wave excitation ratio is zero, are marked 1.
- .s7out1
  - Addition of a separate lift coefficient column for traveling wave excitation in addition to the existing standing wave excitation lift coefficient. It shows the traveling lift coefficient when traveling wave excitation ratio is greater than 0, otherwise '*'.
- .s7out2
  - Adds traveling wave excitation lift coefficient data for every mode/node row. When traveling excitation is off, that field is the existing-style 99; non-excited rows retain this style for both lift coefficients.
- .s7anm
  - Traveling wave excitation results appended to the bottom of the existing results.
- .s7log
  - Now reports standing and traveling total excitation power separately. It prints the traveling excitation power value only when available, otherwise *, and labels the two beta-iteration result streams separately.

### 1.2.2 New Strakes With Marine Growth Lift Curves

- Four CL curves have been added to the common.s7cl file provided with SHEAR7, modeling the effects of marine growths on strakes under different conditions. These were developed based on the results of model testing with various combinations of marine growth on strakes covering different lengths of a 38m long riser at Marintek (OMAE2012-84055):

- 30% marine growth for strakes at subcritical Reynolds numbers
- 60% marine growth for strakes at subcritical Reynolds numbers
- 30% marine growth for strakes at supercritical Reynolds numbers
- 60% marine growth for strakes at supercritical Reynolds numbers

### 1.2.3 Bug Fixes

- NaN values are now properly identified in .s7mds files, providing a clearer error out when they occur.
- Closing SHEAR7 prior to calculation completion, including before providing the input file, will now properly release any network license seats used. Note that this does not include any forced termination via a task manager.

### 1.2.4 Licensing Changes

- From this version onwards, only software license keys will be available. USB dongle hardware licenses are now discontinued.
- Sentinel license manager installer has been updated to properly add the required server URL, removing the need for manually updating the configuration prior to license activation.

# 2 SUMMARY OF NEW FEATURES IN PREVIOUS VERSIONS

## 2.1 NEW IN VERSION 4.12C

### 2.1.1 Improvements

- Implemented compatibility with new software-based licenses.

## 2.2 NEW IN VERSION 4.12B

### 2.2.1 Theoretical Improvements

- Adjustment of Power Zone Amplitude Limit value in example files
- The Power Zone Amplitude Limit value has been adjusted from 0.3 to 0.65 in the example files.
- Older versions of the program recommended using PZAL=0.3, this recommendation has been updated recently as a result of recent research. The analysis of drilling riser data described in OMAE2023-104900 showed that the PZAL needed to be set to larger values between 0.60 to 0.90 but it was not possible to narrow it down further due to incomplete current profile data. The subsequent benchmarking of the 38m SHELL model tests with v4.12 of the program showed that PZAL values of 0.65 work well to predict the secondary excitation regions.

### 2.2.2 Other Improvements

- Inclusion of optional curvature time history output file, *.s7cth
- Added clearer error for non-existent input files. If an input *.s7dat cannot be resolved by Shear7 to an existing file, an output error code 74 will be written to a *.s7out of the same name
- Changes to Shear7 uninstaller to prevent removal of non-installation related files on uninstall
- Addition of Shear7 icons to allow easy identification of Shear7 files and executable
- Added official support for Windows 11
- Windows 8 official support has been discontinued

### 2.2.3 Bug Fixes

- Added an input check on the hydrodynamic diameter value to output an appropriate error if it isn't greater than 0. This prevents the program crashing during calculations.
- Time history generation can no longer be enabled when calculation of fatigue with zero-crossing method is also enabled, as this leads to invalid results.

## 2.3 NEW IN VERSION 4.12A

### 2.3.1 Theoretical Improvements

#### *2.3.1.1 High Reynold's Number Lift Table*

A new lift table for high Reynold's number has been developed for High Reynolds numbers. This lift table has been included as CL Table 10 in the common.s7CL file provided in the <InstallationDir>\Bin and <InstallationDir>\Examples folders.

#### *2.3.1.2 Swap The Order That Power Zone Amplitude Limit (PZAL) And Power Cutoff Are Applied*

This was motivated by work on very long drilling risers. Measurements suggest that a very strong surface current is exciting a high mode number response at the top and a much weaker but deep-submerged current acting over a large portion of the riser excites a very low mode number response.

SHEAR7 could previously simulate a similar scenario by setting the PZAL value and the power-cutoff accordingly. However the low mode number cases (Mode 3,4,5 etc) usually have very small powers when compared to the dominant high mode number case driven by the surface current (Mode 25-30). As a result the power cutoff must be set to a very low value in order to allow the low-mode number cases to pass through to the PZAL comparison step. This very low power-cutoff will then mean that many high-frequency modes will be time-sharing in the primary excitation zone of the SHEAR7 result and is substantially different from the field observation which shows just 2 or 3 modes high frequency modes time-sharing.

With the swap in order now resulting in the PZAL requirement first, any modes that satisfy the PZAL requirement and are situated to one or the other side of the dominant/most powerful modes (belonging to excitation Zone 1) would be assigned to either excitation Zone 2 or 3 depending on their spatial position. The power-cutoff is then be applied to the modes belonging to each of the excitation-Zones 1, 2, 3 separately resulting in the correct number of modes time-sharing in each zone.

Each of the excitation zones now has a dominant mode and the power-cutoff is individually applied within each excitation zone.

### 2.3.2 Other Improvements

- Inclusion of optional displacement time history output file, *.s7dth

### 2.3.3 Bug Fixes

The following bugs were resolved in this version:

- The stress range within the stress time history (.s7sth) output file is twice that within the other SHEAR7 output files (.s7out section 15.1 and 15.4, .s7plt, and .s7str).

- Diameter units incorrectly converted for the c* calculation when using English Units.
- When specifying the calculation option (block 5 line 1) in an input .dat file, a filename should only be required for calculation option 3, a unique-name.mds. For all other calculation options the file is either generated by SHEAR7 (options 0 and 1) or the modes files is named common.mds (option 2), therefore no filename is required to be specified by the user. The SHEAR7 input file parser incorrectly requires a filename to be provided after the calculation option number and causes an input error to be raised if not provided.

# 3 PROGRAM GENERAL DESCRIPTION

SHEAR7 is a mode superposition, VIV response prediction program, which evaluates modes likely to be excited by vortex shedding and estimates the steady state, cross-flow and pure in-line, VIV response in uniform or sheared current flows. For a detailed FAQ relating to the use of SHEAR7 see the SHEAR7 website, www.shear7.com. A list of VIV technical references are supplied in Appendix E of this User Manual.

## 3.1 PROGRAM CAPABILITIES

For most offshore structures it is recommended that the user compute structural natural frequencies and mode shapes in a separate program, such as OrcaFlex, Flexcom, Abaqus or another Finite Element Analysis program and import them into SHEAR7 for VIV analysis. Alternatively, for simple structures, SHEAR7 can internally evaluate natural frequencies and mode shapes of cables and beams with linearly varying or slowly varying tension and with a variety of boundary conditions, including cantilevers and free hanging risers. The beam and cable models with constant or linearly varying tension and pinned ends have been extensively tested. There may be bugs present, especially for some of the less frequently used structural models. The program is capable of evaluating the natural frequencies and mode shapes and VIV response of horizontal catenary cables, and uses an approximate structural model for inclined catenary cables.

The SHEAR7 VIV response prediction includes Root Mean Square (RMS) displacement, velocity, acceleration, RMS stress and fatigue damage rate as well as local drag amplification coefficients. Global and local stress concentration factors may be applied to the riser being modeled. Structures are not required to be of constant cross-section, if a structure is to be modeled with a non-constant cross section the user is required to import the .s7mds file from a Finite Element package. The user may also model sections of structures with VIV suppression devices, fairings or staggered buoyancy modules.

SHEAR7 v4.11 added a beta test version of a varying structural damping “stick-slip” module, appropriate for modeling long flexible ocean structures with helically wound layers such as:

- umbilicals,
- power cables and
- unbonded flexible risers.

By using this module, users can realize potentially larger structural damping values and hence smaller response amplitudes that occur when inter-layer structures are slipping on each other and dissipating energy. More details are contained in Appendix I . This is expected to be applicable for the response prediction of dynamic sections of renewable energy power cables.

## 3.2 SHEAR7 ACADEMIC LICENSE

SHEAR7 is available with an academic license for non-commercial use in academic institutions. The SHEAR7 Academic License lets users avail of the program capabilities listed in Section 3.1 with minor restrictions as detailed throughout the remaining sections of the SHEAR7 User Guide.

## 3.3 VIV SOLUTION METHOD

SHEAR7 can be used to predict the cross flow or pure in-line, vortex-induced vibration response of a long cylinder with varying tension in a sheared flow. The basic solution technique used is modal analysis and power-balance iteration (to account for the non-linear relationship between response and lift coefficient). The physical assumption is that the power input (by lift force) and power output (through damping) for each mode should be in balance in a steady state response. From initial values of lift and damping coefficients, the program finds the lift and damping coefficients in a balanced state through iteration. The converged lift and damping coefficients are then used to compute the structure's response.

## 3.4 VERY LONG CYLINDER MODELING

SHEAR7 is a mode superposition program and executes extremely quickly when only a small number of modes is required in the mode superposition solution. The 'off-diagonal damping correction' introduced in v4.10 and the improvements to the 'distributed amplitude iterations' introduced in v4.11 have addressed the limitations that existed when modeling very long structures where a large number of modes contributed to the total response of the mode super position solution. In an earlier release (v4.7) the historical limitation of 100 modes was increased to 1000 modes and as of v4.11 this limit has been entirely eliminated. The maximum number of spatial segments is limited by the users computer RAM capacity. The maximum allowable number of structural zones and fatigue curves defined are unlimited. However the number of segments defining the fatigue curve is limited to six, which for most applications is more than adequate.

## 3.5 COORDINATE SYSTEM AND CURRENT PROFILE SPECIFICATION

The program assumes that the coordinate system used to specify the axial position along the cylinder is non-dimensional, beginning at x/L = 0.0 and ending at x/L = 1.0. The current profile values in the input *.s7dat* file must be specified in terms of x/L coordinates and must begin with the lowest x/L value and proceed to the highest.

The top end or the bottom end of the structure can be chosen to be x/L=0, as presented in Figure 1. Typically, the minimum tension end is set to x/L=0.

Whichever orientation is selected, if the user is selecting the program to compute natural frequencies and mode shapes, it is critical that the sign of the submerged weight is positive for x/L=0 at the minimum tension end and negative for x/L=0 at the higher tension end (see example in Table 4).

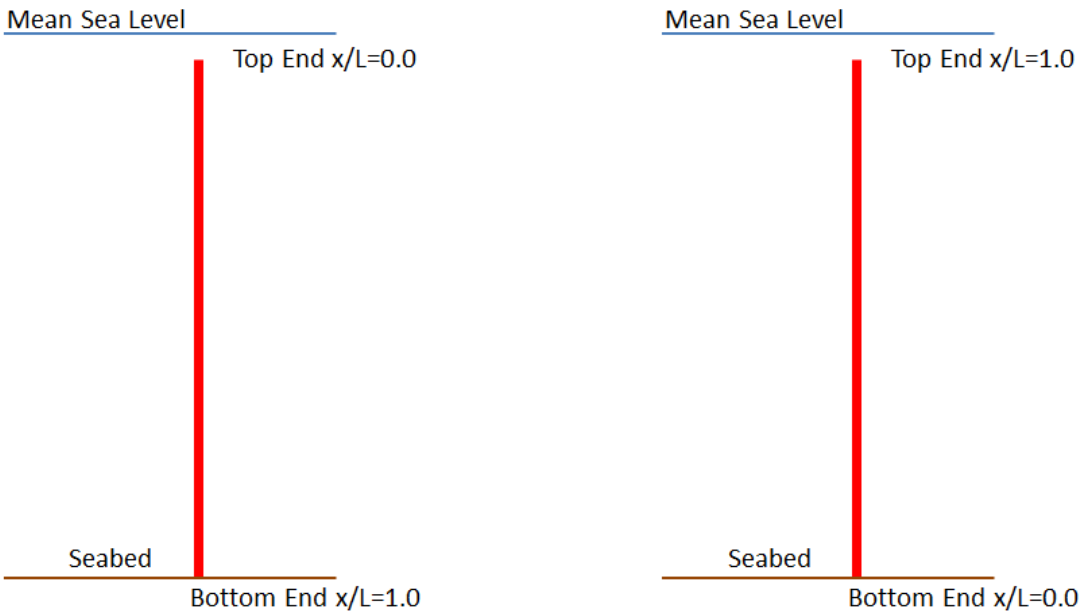



Figure 1: SHEAR7 Coordinate System

Further explanation in the specification of the input files for both coordinate systems is provided in Sections 5.3.9.3, 5.4.2 and 5.5.1.

# 4 INSTALLATION

This section explains how to install and setup SHEAR7. This set of instructions is also provided with the SHEAR7 software in the file README.txt.

SHEAR7 currently supports the following Operating Systems:

- Windows 11.

SHEAR7 no longer supports Windows 10 and prior versions, as Microsoft has ended extended support for this Operating System.

Please note the following SHEAR7 guidance instructions:

- If using a USB license dongle for running SHEAR7 (Note that this is not available for versions newer than v4.12c):
  - **Do not plug in the USB dongle until the installation is complete.**
  - Once the USB dongle is inserted for the first time, you may have to wait a minute for the computer to recognise it.
- Once installation is complete, you can copy the **SHEAR7 executable** and **common.s7cl** file from <InstallationDir>\Bin to any working area on your network or local computer.
- The program needs to be run from your local computer; however the software can reside on a network drive.

The following steps outline the installation procedure:

1. Run **setup.exe** file on the installation CD or download directory.
2. Click **Next** button.
3. Select **Install** for anyone using this computer then click **Next** button.
4. Define destination folder then click **Next** button. It is recommended to use the default directory.
5. Click **Install** button (You may have to wait few minutes).
6. Click **OK** button.
7. Click **Next** button.
8. Click **Finish** button.

## 4.1 SILENT MODE INSTALL/UNINSTALL

A new feature of SHEAR7 v4.11 was that any user may allow SHEAR7 to be installed and uninstalled in silent mode. In this mode the process does not generate any dialog boxes. Installing or uninstalling in silent mode requires no user interaction during either process.

Silent mode is activated by calling the install or uninstall executable with a “/S” argument.

## 4.2 64 BIT EXECUTABLE

SHEAR7 is provided as a 64 bit executable. After installation it is located within "<InstallationDir>\Bin".

- The 64 bit version is named **shear7_5.0b.exe**.

## 4.3 REGRESSION TESTS

Running SHEAR7 regression tests has previously been a required step in the installation process. Beginning with v4.11, running the regression tests is now optional. If the user wishes to run the regression tests, they are provided as a separate download on the SHEAR7 website.

1. If using a USB license dongle for running SHEAR7:
    1. Plug in the USB dongle and wait for the computer to recognize it.
2. Using your internet browser, navigate to www.shear7.com. On the home page you will find a 'Regression Tests' download button, near the SHEAR7 download button.
3. Download and unzip 'Regression Tests' folder.
4. Copy folder "Regression Tests" to your working folder (e.g. Desktop or Scratch drive) .
5. Copy the “shear7_5.0b.exe” from “C:\Program Files\Shear7\5.0b\Bin” to this “Regression Tests” folder.
6. Double click on the "s7regtester.exe" file located within the copied "Regression Tests" folder.
7. Type in “shear7_5.0b.exe” into the open command prompt window and then press Enter.

Once the run is completed check the logfile.txt for the test result.

## 4.4 UNINSTALLING

SHEAR7 can be uninstalled using either of the following:

- From the Windows Settings via Settings > Apps > Apps & Features;
- From the Windows Control Panel via Control Panel > Programs > Programs and Features;
- Directly using the uninstallation program included within the SHEAR7 program directory at <InstallationDir>\uninstall.

In each case follow the steps in the uninstall dialog.

# 5 SPECIFICATION OF INPUT DATA

The SHEAR7 input file is written as a text file and saved as a *.s7dat* file. The input data is divided into six blocks and each block starts with its identification line, which is required by SHEAR7, followed by the input data values.

A typical input file (from example folder "*basic_beam_3.s7dat*") is provided below to explain the input data that is required by SHEAR7. Sections 5.2 to 5.7 presents a line by line description of each block and its input data required to build the SHEAR7 input file. It should be noted that the text after each numerical entry is ignored. When more than one number must be specified on a line, the numbers may be separated by spaces or spaces and commas only (**do not use tabs**). The information shown in red text below corresponds to changes required by version 5.0 as compared with version 4.12. Deletions of existing formats are shown as ~~abcdefgh~~ while new items added start with the word NEW:.

| | | | | | | |
|---|---|---|---|---|---|---|
| NEW: SHEAR7 5.0 Data File For A Tensioned Beam With Boundary Rotational Spring | | | | | | |
| File Name: basic_beam_3.*s7*dat nmodel = 6 pinned w/spring beam. | | | | | | |
| *** BLOCK 1. unit system *** | | | | | | |
| 1 | | | | | | flag for units (English Units) |
| *** BLOCK 2. structural and hydrodynamic data *** | | | | | | |
| 6 | | | | | | flag for structural model (nmodel) |
| 1500 | | | | | | total length of the structure (ft) |
| 100 | | | | | | number of spatial segments |
| 64.0 | | | | | | fluid density (lb/ft$^3$) |
| 0.0000140 | | | | | | kinematic viscosity of the fluid (ft$^2$/s) |
| 0.00300 | | | | | | structural damping ratio |
| 224809.0 | | | | | | effective tension at origin (lbf) |
| 1 | | | | | | no. of zones to define sectional property |
| 0.0000 | 1.0000 | | | | | zone start and end point in x/l |
| 84.0 | 46.0 | 42.0 | | | | hydro, strength, inside diameter (in) |
| 0.3233E+1 | 2296.140 | 166.870 | | | | inertia(ft$^4$), mass(lbf/ft), sbmg wt(lbf/ft) |
| 30022.8 | 1 | | | | | modulus of elasticity (ksi), s-n curve i.d. no. |
| 0.5 | 0.18 | 1.0 | 1 | | | dVR, St No, Cl reduction factor, zoneCLtype |
| 1.0 | 1 | 0.2 | 0.18 | 0.2 | 0 | Ca, DampCoeff0, DampCoeff1, DampCoeff2, DampCoeff3, DampCoeff4 |
| *** BLOCK 3. current data *** | | | | | | |
| 6 | 1.0 | 200 | | | | no. of profile data pts probability profile ID |
| 0.04 | 4.3000 | | | | | location (x/L) and velocity (ft/s) |
| 0.133 | 4.2900 | | | | | location (x/L) and velocity (ft/s) |
| 0.267 | 2.4200 | | | | | location (x/L) and velocity (ft/s) |
| 0.500 | 1.4900 | | | | | location (x/L) and velocity (ft/s) |
| 0.973 | 1.0100 | | | | | location (x/L) and velocity (ft/s) |

| | | | |
|---|---|---|---|
| 1.000 | 1.0000 | | location (x/L) and velocity (ft/s) |
| *** BLOCK 4. s-n and scf data *** | | | |
| 1 | | | No. of S-N curves defined |
| 1 | 1 | | S-N curve I.D., No. of S-N curve segments (API-X') |
| 0.0000 | | | cut-off stress range (ksi) |
| 0.4010E+1 | 0.1000E+9 | | stress range (ksi) cycles to failure |
| 0.4700E+2 | 0.1000E+5 | | stress range (ksi) cycles to failure |
| 1.00 | 0 | 1.00 | global scf, flag for bs-curv factor, bs-curv loading factor |
| 0 | | | no. of local stress concentration positions |
| *** BLOCK 5. computation/output option *** | | | |
| 1 | | | calculation option |
| 0.0 | 1.0 | 0.1 | locations for output summary |
| 0 | | | gravitational acceleration |
| 0.05 | 0.65 | | power cutoff, primary zone amplitude limit |
| 1.0 | | | power ratio exponent (0 - equal probabilities;1 - power ratio) |
| 3.33 | 0.4 | | Higher harmonics factor, Higher harmonics threshold |
| 0.5 | | | NEW: Traveling wave excitation ratio |
| 4 | | | Beta control number (0 = no beta iterations, up to 10 for the number of beta iterations) |
| 0 | | | flag for selecting the riser diameter for fatigue (0=OD, 1=ID) |
| 84 | | | reference diameter for $A_t$* calculation (m) |
| 0 | | | flag for importing nodal effective tension and mass, (1=y;0=n) |
| 0 | | | flag for MATLAB animation data output, (1=yes;0=no) |
| 0 | | | flag for generating *.s7log file, (1=y;0=n) |
| 0 | | | flag for generating *.s7dmg file, (1=y;0=n) |
| 0 | | | flag for generating *.s7fat file, (1=y;0=n) |
| 0 | | | *.s7out file selection, (0=*.s7out, 1=*.s7out1, 2=*.s7out1+*.s7out2) |
| 0 | | | flag for calculating fatigue with zero-crossing method (1=y;0=n) |
| 0 | | | flag for pure in-line fatigue calculation (1=y;0=n) |
| 0 | | | flag for generating *.s7str file, (1=y;0=n) |
| 1 | | | flag for non-orthogonal damping (1=y;0=n) |
| 0 | | | flag for unique named lift table file |
| 0 | 0.01 | | flag for stick-slip hysteresis, (0=n,1=y, 2=y(unique name)) |
| 0 | | | flag for generating *.curv file, , (0=n,1=y) |
| 0 | | | flag for generating *.zeta-hyst file, (0=n,1=y) |
| *** BLOCK 6. supplemental data *** | | | |
| 0.10E+07 | | | rot stiffness at x=L:lbf-ft/rad |
| 0.10E+07 | | | rot stiffness at x=0:lbf-ft/rad |

if nmodel = 6 (pinned-pinned tensioned beam w/two rot springs) provide rotational stiffness at each end

| | |
|---|---|
| if nmodel = 9 (free-pinned (w/spring) beam w/varying tension origin at free end) provide translational stiffness at x = L | |
| if nmodel = 19 (free-pinned (w/spring) beam w/o tension origin at free end) provide translational stiffness at x = L | |
| if nmodel = 33 (inclined cable) provide chord inclination (angle) | |
| *** BLOCK 7. time history data *** | |
| 1 | flag for time history outputs (.s7sth, .s7dth, .s7cth), (1=y;0=n) |
| TOTAL=3600.0 | total time, (optional) |
| SAMPLE=1.0 | sample period, (optional) |
| NODES=1:5,251,1884 | output node ranges, (optional) |
| SEED=123 | random number seed, (optional) |

Note: Version 4.12 .s7dat files may be converted to version 5.0 .s7dat by using the program convert_v412_to_v50.exe, which is provided with the program. This will add and set the new traveling wave excitation ration parameter to 0.5. Manually setting this value to 0 will result in almost identical results as v4.12c.

Example input files are included in the distribution download, in the examples folder. Provisions are made so that SHEAR7 may be run in batch mode. See the sample datafile.bat file within the distribution.

## 5.1 VERSION CONTROL

The first string of the first line within the input .*s7*dat file must be “SHEAR7 5.0”. This allows the user to know exactly which version of input file they have, and ensures older version are not run by accident. SHEAR7 version 5.0 will report an error if this is not present. The remainder of lines one and two in the version control block can be used to give a brief description of the model as per previous SHEAR7 versions.

## 5.2 BLOCK 1 – UNIT SYSTEM

Block 1 defines the unit system to be used in the analysis. There are two options for the user to choose as follows:

- 0 for SI units
- 1 for English units

The selection of the unit system must be strictly adhered to for the entire data set. Always use the units consistent with the system designated in this line. For each input quantity the dimensions are defined according to Table 1.

Table 1: Input Data Units

| Input Data | SI | English |
|---|---|---|
| Structure Length | m | ft |
| Density | $kg/m^3$ | $lb/ft^3$ |
| Kinematic Viscosity | $m^2/s$ | $ft^2/s$ |
| Effective Tension or Tension Variation | N | lbf |
| Diameter | m | in |
| Inertia | $m^4$ | $ft^4$ |
| Mass per Unit Length (in air including contents) | kg/m | lb/ft |
| Submerged Weight per Unit Length | N/m | lbf/ft |
| Elastic Modulus | Pa | ksi |
| Current Velocity | m/s | ft/s |
| Stress | Pa | ksi |
| Gravitational Acceleration | $m/s^2$ | $ft/s^2$ |
| Curvature | rad/m | rad/ft |

The following is a list of unit definitions:

- SI
  - m – meter
  - kg – kilogram
  - s – second
  - N – Newton
  - Pa – Pascal
- English
  - ft – feet
  - lb – pound
  - s – second
  - lbf – pounds force
  - in – inch
  - ksi – kilopound per square inch

## 5.3 BLOCK 2 – STRUCTURAL AND HYDRODYNAMIC DATA

Block 2 defines the structural and hydrodynamic data to be used in the analysis. The following Sections provide a description of the required inputs for Block 2.

The default set of parameters are presented in Appendix A.

### 5.3.1 Flag For The Structural Model

For most offshore structures it is recommended that the user compute structural natural frequencies and mode shapes in a separate program, such as Orcaflex, Flexcom, Abaqus or another FEA program and import them into SHEAR7 for VIV analysis. When importing natural frequencies and mode shapes, Nmodel is not used by the program. Therefore the value used is not important, however it is suggested to use a value such as, 999, to indicate that the input is not being used.

Alternatively, for simple structures, SHEAR7 can internally evaluate natural frequencies and mode shapes of cables and beams with linearly varying or slowly varying tension and with a variety of boundary conditions, including cantilevers and free hanging risers. Here, the flag **nmodel** is used in the program to specify the type of structure to be modelled.

The definition of a simple structure, suitable for utilising SHEAR7's internal structural computation of natural frequencies and mode shapes includes:

- Constant structural (steel) cross section
- No tapered joints
- Slowly varying tension properties
- No distributed buoyancy.

The structural models presented in Table 2 may be selected by entering the appropriate integer at this line in the input data file. Most applications are for beams under varying tension and use **nmodel = 1**. Models are grouped into four Categories, A to D. Not all integers in a group, such as those in the group 0 to 9 have been used. This allows for additional models to be added later in each group. The names of example data files, which demonstrate some of the options, are provided in Table 2.

The choice of which model to use is left to the user. In general, if the natural frequency, which is closest to the maximum vortex shedding frequency, is governed dominantly by tension, one may use finite cable models. If bending stiffness is important, use the finite beam model. The SHEAR7 program will estimate the relative importance of EI and T and will suggest in the .s7out file whether a beam or a cable model should be used. This is discussed further in Section 7.1.

Table 2: SHEAR7 – Structure Models Available

| Group | Group Description | Nmodel | Nmodel Description | Example File |
|---|---|---|---|---|
| A | Cylinders with linearly varying tension | 0 | Pinned-pinned cable, origin at minimum tension end | basic_cable.s7dat |
| | | 1 | Pinned-pinned beam, origin at minimum tension end | basic_beam_2.s7dat<br>basic_beam_1.s7dat |
| | | 2 | Free-pinned beam, origin at free end | - |
| | | 6 | Pinned-pinned beam with two rotational springs[1] | basic_beam_3.s7dat |
| | | 9 | Free-pinned (w/rotational spring[1]) beam, varying tension, origin at free end | - |
| B | Cylinders with constant tension | 10 | Pinned-pinned cable, origin at either end | - |
| | | 11 | Pinned-pinned beam, origin at either end | - |
| | | 19 | Free-pinned (w/rotational spring[1]) beam, origin at free end | - |
| C | Cylinders with no tension | 22 | Free-pinned beam, origin at free end | - |
| | | 23 | Clamped-free beam, origin at clamped end | - |
| | | 24 | Clamped-pinned beam, origin at clamped end | - |
| | | 25 | Clamped-clamped beam, origin at either end | - |
| | | 26 | Sliding-pinned beam, origin at sliding end | - |
| D | Catenary cables with no bending stiffness | 30 | Constant tension, horizontal catenary | - |
| | | 33 | Constant tension, inclined catenary | scr_inclined_cat.s7dat |
| E | Use of a .s7mds file | 999[2] | .s7mds file is used to import the modal response | |

Notes:

1. When rotational springs are included in the structural model, Block 6 has to be filled to include the spring stiffness. Line 1 is for the spring constant at x/L=1.0 and line 2 is at x/L=0.
2. Any "Nmodel" code could be used when the .s7mds file is used to import the model response and the program will not stop or issue a warning, however for easily visualization that an external file is being used, it is suggested that users use the code 999.

### 5.3.2 Total Length Of The Structure

Defines the total length of the structure.

The following limitation is applied against SHEAR7 Academic Licenses:

- The total structural length is limited to a maximum of 800 m (SI Units) / 2624 ft (English Units)

### 5.3.3 Number Of Spatial Segments (NS).

Defines the number of segments in the structure.

The inverse of NS is the dimensionless spatial resolution, DELX. The total number of nodes is NS+1. There used to be a limit of 2000 on NS, but that limit has been removed and accordingly the user can specify NS of his or her choice. The following remarks should be noted:

- If the user-input **NS** is 0, the program will automatically set it to **500**.
- If the user-input **NS** is a non-zero positive integer it will be used in the program.
- SHEAR7 requires **ten nodes per minimum computed wave length** in order to compute the VIV response of the structure. If SHEAR7 identifies that there is less than ten nodes per computed wave length, the program will stop and the following error message will be presented in the .s7out file.
    - *"The number of spatial segments is less than the estimated minimum number required by SHEAR7.*

      *Number of spatial segments:* *X*

      *Required number of spatial segments:* *Y*

      *The program stops."*
- Item 17 of the .s7out file provides a suggested minimum number of segments that should be used, based on a requirement of ten nodes per minimum computed wave length.

### 5.3.4 Fluid Density

Defines the density of the fluid surrounding the cylinder.

### 5.3.5 Kinematic Viscosity Of The Fluid

Defines the kinematic viscosity of the fluid surrounding the cylinder.

### 5.3.6 Structural Damping Ratio

This is the structural damping ratio specified for the cable or beam. It would correspond closely to the value that one might measure in a vacuum. For most cylinders under high tension in water, this value is usually very small (order of 0.003). Except for uniform flow cases the hydrodynamic

damping is usually much larger. The value 0.01, for example, means the same as 1% of critical damping.

It should be noted that flexible risers and umbilicals have a higher structural damping due to friction between the helically layered components, however, currently there is limited data and guidance on structural damping coefficients for these structures.

### 5.3.7 Effective Tension At Origin

This is the effective tension of the structure at its origin (x/L=0).

### 5.3.8 Number Of Sectional Zones

Defines the number of sectional zones that the user selects the structure to be made of. The structure may have multiple zones with different structural dynamic and hydrodynamic properties in each zone.

### 5.3.9 Zone Structural And Hydrodynamic Properties

Each zone requires six lines of input data. Each of these lines are described in details in Sections 5.3.9.1 to 5.3.9.7.

#### *5.3.9.1 Zone Start And End Point In X/L*

This line has two numbers, which specifies the beginning and end of the zone in x/L coordinates. Figure 2 presents an example of a riser with 3 zones and its respective start and end points of each zone in x/L.

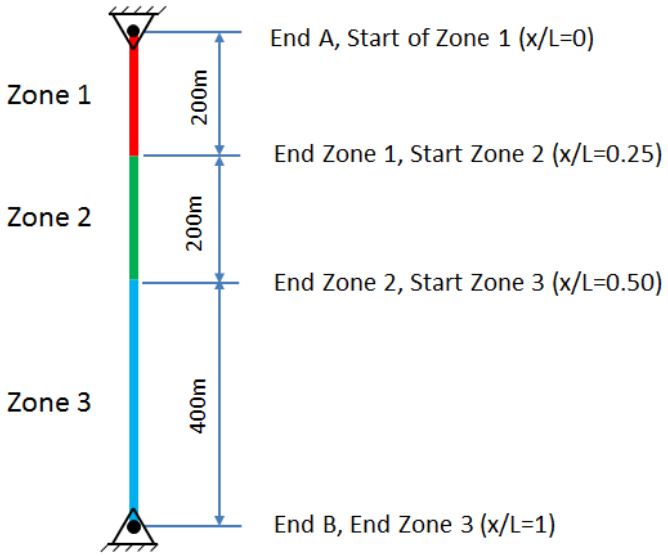



Figure 2: Example of Zone Start and End Point in x/L

When specifying the x/L coordinates of each zone the user should carefully choose the number and location of the nodes to represent the model. SHEAR7 assigns the nodes to each of the zones specified in Block 2 and the following possibilities are possible:

- Both ends in zone – both ends of a given segment is within the allocated zone. Segments 1, 3 and 4 of Figure 3.
- One end out of zone – one end of the segment is in the allocated zone while the other end will be allocated to the previous zone. Segment 2 of Figure 3.

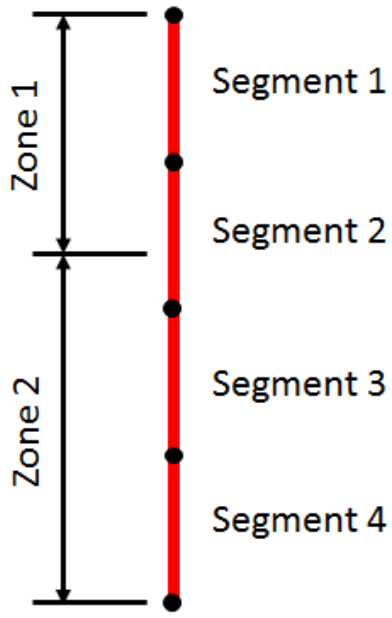



Figure 3: Example 1 of Correct Segment Allocation

It should be noted that when using small zones to define the structure, caution should be used to define the nodal segmentation. If a zone does not have a node allocated to it, as per Segment 2 of Figure 4, the program will stop and return the following error message:

- "No segments defined in mds file have been

  *assigned to zone defined in dat file.*

  *The program stops*".

In all cases it is highly recommended to have zone sizes larger than segment sizes.

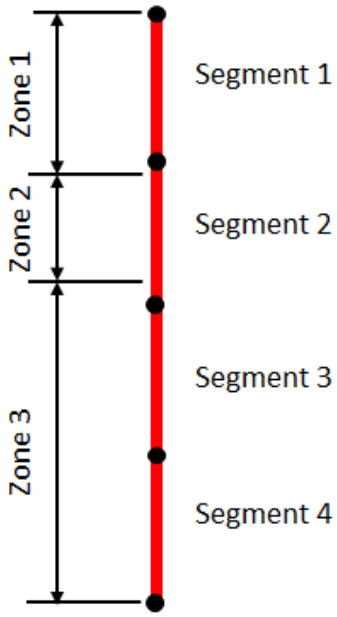



Figure 4: Example 2 of Incorrect Segment Allocation

### *5.3.9.2 Hydrodynamic, Strength Outer And Inner Diameters*

This line defines three diameters that are necessary to describe the structure as follows:

- Hydrodynamic diameter ($H_{OD}$) - The hydrodynamic diameter of the cylinder and is used to compute the Strouhal frequency, added mass, hydrodynamic damping and lift force for this zone. It can be the diameter of a buoyancy module, insulation material, outer diameter of an umbilical, etc. When modeling strakes the hydrodynamic diameter should be set as the strake sleeve not the outer edge of the strake fin.
- Strength outer diameter ($S_{OD}$) – The outer diameter of the strength member which is used to calculate the member stress. It affects only the dynamic stresses and the fatigue damage values computed. Examples of its use include the outer diameter of an SCR inside of the buoyancy module, steel tube outer diameter inside of an umbilical.
- Strength inner diameter ($S_{ID}$) – The inner diameter of the strength member and is needed for computing the cross sectional area of the strength material.

It should be noted that the outer strength diameter is not necessarily a structure's hydrodynamic diameter, as in the case of a riser with flotation material surrounding the strength member. This is presented in Figure 5, where the strength outer and inner diameter is constant throughout the length, however the hydrodynamic diameter changes from riser only to riser with buoyancy module sections.

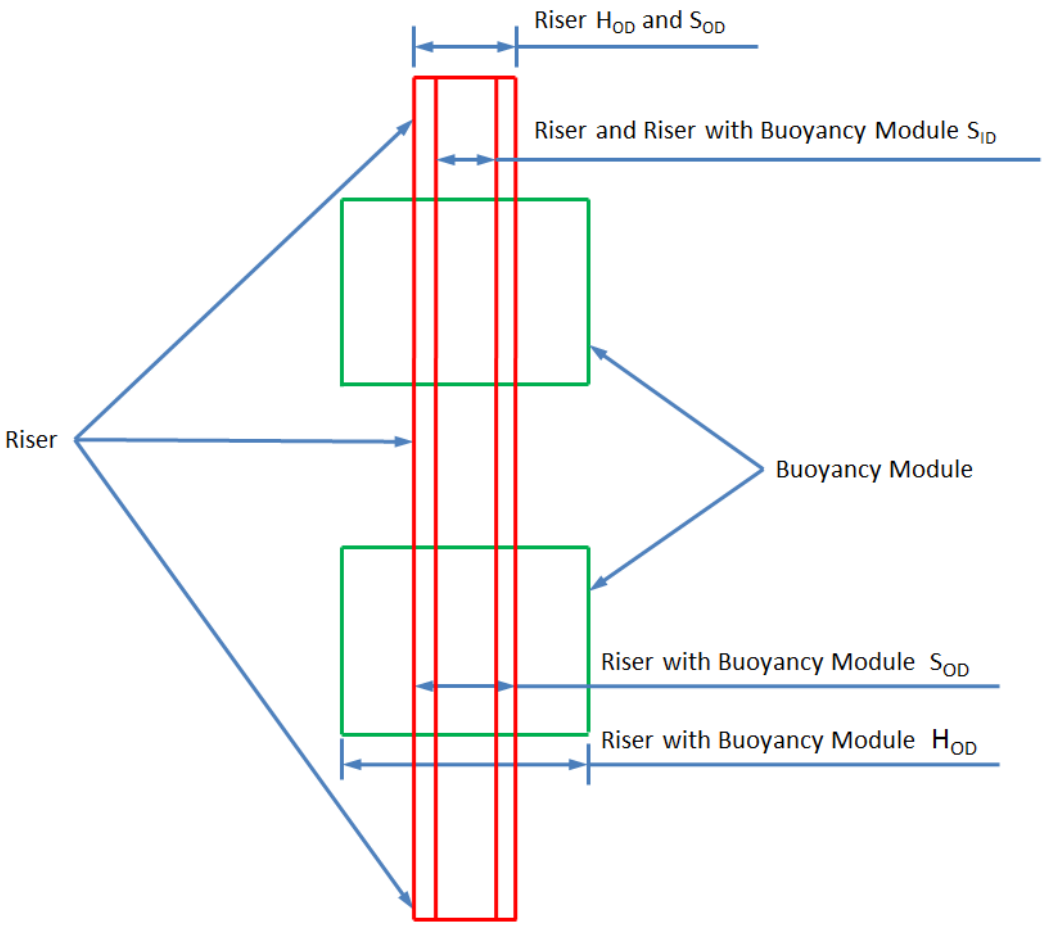



Figure 5: Example of Diameters in a Riser with Buoyancy Module Sections

Figure 6 presents an example of a riser with insulation where the hydrodynamic, strength outer and inner diameter is constant throughout the length of the riser with insulation.

The example of insulation modeling in Figure 6 could also be used to represent marine growth or FBE (Fusion Bonded Epoxy).

In the case where the user wishes to compute fatigue damage rate at the inside diameter, for instance applications with Sour Service, the user can specify the inside diameter as the strength outer diameter, and it will not change the VIV response of the structure, but just the location where the fatigue damage rate is computed.

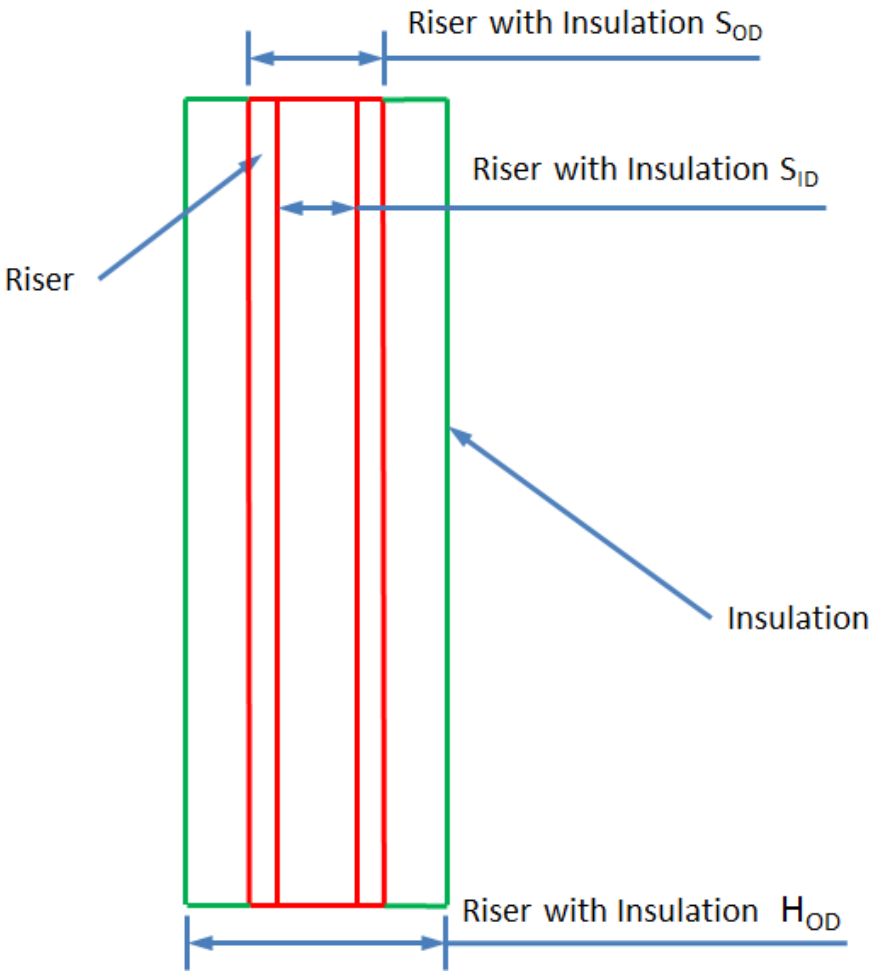



Figure 6: Example of Diameter in a Riser with Insulation Section

### *5.3.9.3 Inertia, Mass, Submerged Weight*

This line defines the inertia, mass per unit length in air and submerged weight per unit length of the structure. These are used as follows:

- Inertia (I) – It is the effective area moment of inertia of the structure. This includes all tubular structures for a flexible riser and umbilical. The *inertia* is used when SHEAR7 computes the natural frequency of the structure. It is not calculated based on the $S_{OD}$ and $S_{ID}$ provided in the previous line. However, in Item 4 of the .s7out file, *inertia* is computed based on the $S_{OD}$ and $S_{ID}$ as given. This is useful as a check for simple cylindrical structures, in which case the input value and the computed values for *inertia* in these cases should be the same. NOTE: When importing the .s7mds file from another program the *inertia* value is not used in the SHEAR7 analysis. See Section 5.6.1.1 for a complete list of input parameters not required when importing an .s7mds file.

- Mass – It is the mass per unit length in air of the structure including contents. The mass (or weight) per unit length is used when SHEAR7 computes the natural frequencies and mode shapes. **When importing the .mds file, the mass is used in a modal mass calculation.**

- Submerged weight per unit length or tension variation – For sections of a structure in the water this is the weight in water per unit length including contents. For sections of a structure that are above water level this is the weight in air per unit length including contents. This number effectively specifies the amount the tension changes per unit length along the structure.

    - The tension variation is assumed to be of the form T(x) = TO+TLINCO*x with TO being the tension at the beginning of the structural zone. TLINCO may be positive or negative. A positive sign indicates that the tension increases with increasing x/L. A negative sign means the tension decreases with increasing x/L. Therefore, the sign of the submerged weight per unit length depends on how the user defines the origin of the model. Table 3 provides an example of the structure's properties and Table 4 shows how it should be entered in the input line for "*Inertia , Mass, Submerged Weight*" in SHEAR7 for both coordinate systems.

**NOTE:** **If effective tension in the structure is found to be negative, the program will print out a warning in the .s7out file.**

Table 3: Example Of Inertia, Mass And Submerged Weight

| | | |
|---|---|---|
| Bare Joint | Inertia ($m^4$) | 0.0008637 |
| | Mass (kg/m) | 687.8 |
| | Submerged Weight (N/m) | 4114.6 |
| Buoyancy Joint | Inertia ($m^4$) | 0.0008637 |
| | Mass (kg/m) | 970.0 |
| | Submerged Weight (N/m) | -501.7483 |

Table 4: Example Of SHEAR7 Input Line For Inertia, Mass And Submerged Weight

| | | | | | |
|---|---|---|---|---|---|
| X/L=0 Set at Top End (Highest Tension) | Bare Joint | 0.0008637 | 687.8 | -4114.6 | inertia($m^4$), mass (kg/m), sbmg wt(N/m) |
| | Buoyancy Joint | 0.0008637 | 970.0 | 501.7483 | |
| X/L=0 Set at Bottom End (Lowest Tension) | Bare Joint | 0.0008637 | 687.8 | 4114.6 | |
| | Buoyancy Joint | 0.0008637 | 970.0 | -501.7483 | |

#### 5.3.9.4 Modulus Of Elasticity And S-N Curve Identification Number

This line defines the modulus of elasticity and S-N Curve Identification Number of the structure. These are used as follows:

- Modulus of elasticity (E) – This is the modulus of elasticity of the strength member to be used in the computation of the stress and damage rate. The modulus of elasticity is also used when SHEAR7 computes the natural frequency and mode shape of the structure.

- S-N Curve Identification Number – This is the identification number of the S-N Curve that is used in the fatigue calculation for the structural zone in question. The identification number of any of the S-N Curves defined in Block 4 can be used. See Section 5.5.2 for further detail.

#### 5.3.9.5 Reduced Velocity Bandwidth, Strouhal Number, Lift Coefficient Reduction Factor, Zone CL Type

This line defines the zone specific reduced velocity bandwidth, the Strouhal number, the lift coefficient reduction factor, and the CL table. These are used as follows:

- Reduced Velocity Bandwidth (dVR) – This is the width of the band, expressed as a fraction of $Vr_{crit}$ that will be used to define which possible modes could lock-in. The bandwidth is centered on a critical reduced velocity which is defined as, $Vr_{crit} = 1/St$. Therefore, if the *.s7dat* file specifies 0.4 as the lock-in bandwidth, then the band extends plus and minus 20% either side of $Vr_{crit}$. Figure 7 presents an example of how the bandwidth is applied to the structure's response, where the bands show the potential lock in range limits for each mode.

In the Miami-DeepStar tests with a high mode number model, the observed reduced velocity bandwidth was approximately 0.4. Other VIV model tests in uniform flow on flexible cylinders have also shown that the reduced velocity bandwidth is typically 0.25 to 0.35.

A broader reduced velocity range increases the size and correlation length for each mode's power-in region. The bandwidth may be quite broad for low-density cylinders under low mode number lock-in conditions in nearly uniform flow.

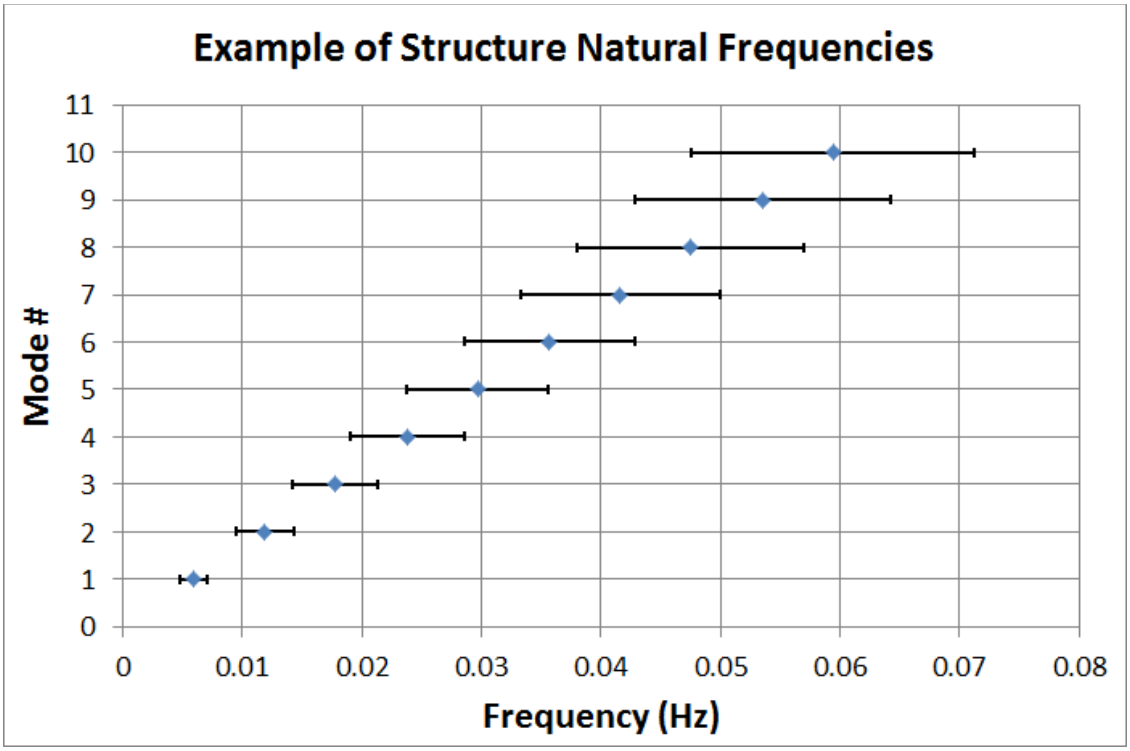



Figure 7: Example of Structure Natural Frequencies

- Strouhal Number (St) - The Strouhal number uniquely defines the relationship of flow velocity and cylinder diameter to the local vortex shedding frequency. For vibrating cylinders at subcritical Reynolds numbers, the Strouhal number varies between 0.14 and 0.18. Above about 100,000 in Reynolds number the Strouhal number for stationary cylinders varies erratically in published data from about 0.2 to 0.5. Recent model tests reveal that the Strouhal number for freely vibrating cylinders varies from about 0.14 to 0.18 for Reynolds numbers varying from 20,000 to over 1 million.

The Strouhal number must be specified as a number, such as 0.18. Code numbers 100, 200 and 300 that were used in earlier versions are now disabled. If any of those codes are used SHEAR7 will stop and the following message will be displayed in the *.s7out* file:

  - *"Strouhal code 200 is disabled in this version of Shear7. Fortran READ error: 999"*
  - *"Not a valid Strouhal number code. The program stops."*

- Lift coefficient reduction factor – The program allows the user to modify the lift coefficient iteration scheme. The lift coefficient reduction factor is multiplied by the Cl value in the Cl tables. Thus a value less than one reduces the value of Cl at all A/D and frequency ratio values by the same factor. A value of greater than 1.0 may be used to enhance the lift coefficient in the iteration.

- Lift Coefficient Table – It specifies which Cl table from the *common.s7cl or <unique-name>.s7cl* table file. Table 5 presents the lift coefficient tables available within SHEAR7. The user can also specify their own lift coefficient curve and this process is described in Appendix B.

Table 5: CL Curves Available

| Lift Coefficient Table | VIV Response | Condition | Description |
|---|---|---|---|
| 1 | Cross-flow | Bare | Default values of lift coefficient for bare cylinder |
| 2 | Cross-flow | Bare | Lift curve based on curves which were fitted to the measured data on bare cylinders. It will produce smaller response predictions than Table 1. It is based on mean values of measurements, and hence will produce mean value estimates of response |
| 3 | | | Supplied as a dummy table for users to change |
| 4 | Cross-Flow | Bare | Fit to the 2015 High Reynolds number data |
| 5 | Cross-flow | Strake | Less conservative approximation to the performance of 25% high, 15 D pitch strakes, manufactured by AIMS International[1, 2] |
| 6 | Cross-flow | Strake | 25% high, 17.5 D pitch strakes in good condition |
| 7 | In-Line | Bare | In-line excitation model for circular sections which will over estimate that of Table 8 |
| 8 | In-Line | Bare | In-line excitation model for circular sections |
| 9 | In-Line | LGS [3] | In-line LGS 6.2% model for risers, rigid spools and pipes, sub-critical Reynolds number |
| 10 | Cross-flow | LGS [3] | Cross-Flow LGS 6.2% for riser and pipe LGS, post-critical Reynolds number |
| 11 | Cross-flow | LGS [3] | Cross-Flow LGS 3.8% for drilling riser buoyancy, post-critical Reynolds number |
| 12 | Cross-flow | LGS [3] | Cross-Flow LGS 3.8% for drilling riser buoyancy, sub-critical Reynolds number |
| 13 | Cross-flow | Strake | 30% marine growth for strakes at subcritical Reynolds numbers[4] |
| 14 | Cross-flow | Strake | 60% marine growth for strakes at subcritical Reynolds numbers[4] |
| 15 | Cross-Flow | Strake | 30% marine growth for strakes at supercritical Reynolds numbers[4] |

Table 5: CL Curves Available

| Lift Coefficient Table | VIV Response | Condition | Description |
|---|---|---|---|
| 16 | Cross-Flow | Strake | 60% marine growth for strakes at supercritical Reynolds numbers[4] |

Notes:
1. With 100% coverage, these strakes totally suppressed VIV at subcritical Reynolds numbers during the Miami and Lake Seneca Deepstar/MIT tests.
2. Table 5 is intended to be conservative, but much less so than Table 6. Table 5 will result in hydrodynamic damping for A/D values greater than 0.15 in the power-in region, and will permit a maximum value of CL of 0.1 at an A/D=0. Thus this strake model will cause some positive power in at low A/D and substantial damping at A/D over 0.15.
3. LGS: refer to Appendix J
4. The strakes with marine growth lift curves were developed based on the results of model testing with various combinations of marine growth on strakes covering different lengths of a 38m long riser at Marintek (OMAE2012-84055).

#### 5.3.9.6 Added Mass Coefficients And Hydrodynamic Damping Coefficients

This line defines the zone specific added mass and hydrodynamic coefficients. These are used as follows:

- Added mass coefficient – The added mass coefficient should be adjusted to account for external added mass as well as for the mass trapped in floodable voids in the cylinder, if not already included in the in-air weight. A value of 1.0 implies an added mass equal to the mass displaced by a solid cylinder of the specified external hydrodynamic diameter. Note, added mass is known to be dependent on the reduced velocity. Therefore, no single value is known to be the best for this application.

In SHEAR7 the added mass primarily affects the predicted natural frequencies. The results are most sensitive to added mass when the density of the structure is low, such as neutrally buoyant risers.

SHEAR7 does not iterate to find the added mass for each mode and reduced velocity distribution; as a consequence, the program is not ideally suited to replicate experimental results exactly at low mode number within a uniform flow.

- Hydrodynamic damping coefficients – Five parameters are required to compute the hydrodynamic damping of the structure within SHEAR7:
  - The Reynolds number dependent still water damping;
  - The A/D dependent still water damping;
  - Damping for low reduced velocity regions;
  - Damping for high reduced velocity regions; and
  - Damping for axial flow.

The five values are represented as DampCoeff0, DampCoeff1, DampCoeff2, DampCoeff3 and DampCoeff4 respectively.

When a section of the structure is not part of the power-in region, then the program will use the damping coefficients specified in that structural zone for the sectional damping calculations.

- To enable purely axial flow damping, the user can switch off the Reynolds number dependent still water damping term by setting it to 0.0. The damping terms appear in Appendix F. An illustration of how they are used is shown in the example files.
- **It is noted that the axial flow damping capability now available since SHEAR7 version 4.9 remains as an experimental feature and is yet to be fully verified. Further testing has been planned for calibration against other model tests and field data. Although Axial Damping Coefficients are available from regulations associated with offshore analysis, these have not been verified for VIV predictions in SHEAR7. It is recommended that users set this parameter to 0.0 for their analyses, unless alternate experimental data is available.**

### *5.3.9.7 Multiple Zones*

When defining multiple zones, first the number of zones needs to be defined, then the subsequent lines should consist of the six lines of data that define each zone. If, for example, three zones are specified (line 8 of BLOCK 2), then after one line with a 3 in it, three groups of six lines of data must follow with no blank lines between groups. An example BLOCK 2 with three zones can be seen in Table 6.

Table 6: Multiple Zone Example

| | | | | | | |
|---|---|---|---|---|---|---|
| *** BLOCK 2. structural and hydrodynamic data *** | | | | | | |
| 6 | | | | | | flag for structural model |
| 1500 | | | | | | total length of the structure (ft) |
| 100 | | | | | | number of spatial segments |
| 64.0 | | | | | | volume weight of the fluid (lbf/ft$^3$) |
| 0.0000140 | | | | | | kinematic viscosity of the fluid (ft$^2$/s) |
| 0.00300 | | | | | | structural damping coefficient |
| 224809.0 | | | | | | effective tension at origin (lbf) |
| 3 | | | | | | no. of zones to define sectional property |
| 0.00 | | 0.25 | | | | zone start and end point in x/L |
| 84.0 | | 46.0 | 42.0 | | | hydro strength inside diameter(in) |
| 3.233 | | 2296.140 | 166.870 | | | inertia(ft$^4$) mass(lb/ft) sbmg wt(lb/ft) |
| 30022.8 | | 1 | | | | modulus of elasticity (ksi), S-N Curve I.D. No. |
| 0.5 | | 0.18 | 1.0 | 1 | | dVR, St No, Cl reduction factor, zoneCLtype |
| 1.0000 | 1 | 0.2 | 0.18 | 0.2 | 0 | Ca, DampCoeff0, DampCoeff1, DampCoeff2, DampCoeff3, DampCoeff4 |
| 0.25 | | 0.50 | | | | zone start and end point in x/L |
| 92.0 | | 46.0 | 42.0 | | | hydro strength inside diameter(in) |
| 3.233 | | 2296.140 | 166.870 | | | inertia(ft$^4$) mass(lb/ft) sbmg wt(lb/ft) |
| 30022.8 | | 1 | | | | modulus of elasticity (ksi), S-N Curve I.D. No. |
| 0.5 | | 0.18 | 1.0 | 1 | | dVR, St No, Cl reduction factor, zoneCLtype |
| 1.0000 | 1 | 0.2 | 0.18 | 0.2 | 0 | Ca, DampCoeff0, DampCoeff1, DampCoeff2, DampCoeff3, DampCoeff4 |
| 0.50 | | 1.00 | | | | zone start and end point in x/L |
| 84.0 | | 46.0 | 42.0 | | | hydro strength inside diameter(in) |
| 3.233 | | 2296.140 | 166.870 | | | inertia(ft$^4$) mass(lb/ft) sbmg wt(lb/ft) |
| 30022.8 | | 1 | | | | modulus of elasticity (ksi), S-N Curve I.D. No. |
| 0.5 | | 0.18 | 1.0 | 1 | | dVR, St No, Cl reduction factor, zoneCLtype |
| 1.0000 | 1 | 0.2 | 0.18 | 0.2 | 0 | Ca, DampCoeff0, DampCoeff1, DampCoeff2, DampCoeff3, DampCoeff4 |

## 5.4 BLOCK 3 – SPECIFICATION OF CURRENT PROFILES

Block 3 defines the current profile data to be used in the analysis. The following considerations should be taken into account when defining the current profile:

- SHEAR7 does not account for variations in current direction or for current reversal. It is suggested to put in the absolute value of a profile which has a current reversal. Do not input negative values of current.
- The velocity profile is assumed to be from a single direction and to be perpendicular to the axis of the structure. If the flow is not perpendicular, the user may choose to resolve the vector component perpendicular to the axis prior to inputting the current profile. Recent research suggests that the VIV excitation diminishes rapidly with current angle greater than 45° to the riser.

### 5.4.1 Current Data – Line 1

The first line of Block 3 begins with three numbers as follows:

a) The number of points specifying the profile. As a minimum two points are required to define the current profile along the structure.

b) Annual probability of occurrence. It defines the probability of the occurrence of this current profile in one year. This quantity is multiplied by the computed damage rate before it is given in the output file. If one uses 1.0 in the input, the final damage rate is not affected.

c) Current profile identification. This number is reported in the output file to help users with profile bookkeeping and it is not used in the program.

### 5.4.2 Current Profile Data – Line 2 Through End Of The Current Profile

The second line onwards specifies the current profile throughout the structure length. A pair of points is used to define the profile. The current profile is piecewise linear between the specified points. Only one pair of numbers are allowed per line. The current profile is specified as follows:

a) x/L location, starting with the minimum value of x/L, which is usually 0.0 and increases to the maximum value of x/L for which the current is specified. If the ascending order of x/L is not followed, the program will stop and the following message will be displayed in the .s7out file:

   - *"To specify a current profile, x/L must be in ascending order. Your input is invalid. The program stops."*

b) Current velocity for the given x/L location.

It should be noted that when specifying the current profile within SHEAR7, three types of flow regions are available as follows:

- Section in a flow region, which has associated with it hydrodynamic damping and added mass. Tables 7 and 8 present example of this case.
    - Table 7 presents the structure with both ends in the water and current applied to the entire structures length. This means that the entire structure length will account for hydrodynamic damping and added mass. Table 8 presents the same scenario, however the x/L origin changed to be '0' at the bottom of the structure.
- Section in still water, which also has hydrodynamic damping and added mass associated with it. Table 9 presents an example of this case.
- Section not in the water, where there is neither hydrodynamic damping nor added mass. Tables 10 and 11 present examples of this case.

In a region which the flow is specified, including zero speed, there is hydrodynamic damping and added mass. If a region is not specified at the top or bottom of the profile, it is assumed to be out of the water, and has no hydrodynamic damping or added mass.

In order to better understand the flow regions above, four examples of current profiles are provided below.

Table 7: Current Definition – Example 1

| | | | |
|---|---|---|---|
| 6 | 1.0 | 1 | no. of profile data pts probability profile ID |
| 0.0 | 1.0 | | location (x/L) and velocity (ft/s) |
| 0.2 | 0.8 | | location (x/L) and velocity (ft/s) |
| 0.4 | 0.6 | | location (x/L) and velocity (ft/s) |
| 0.6 | 0.4 | | location (x/L) and velocity (ft/s) |
| 0.8 | 0.2 | | location (x/L) and velocity (ft/s) |
| 1.0 | 0.0 | | location (x/L) and velocity (ft/s) |

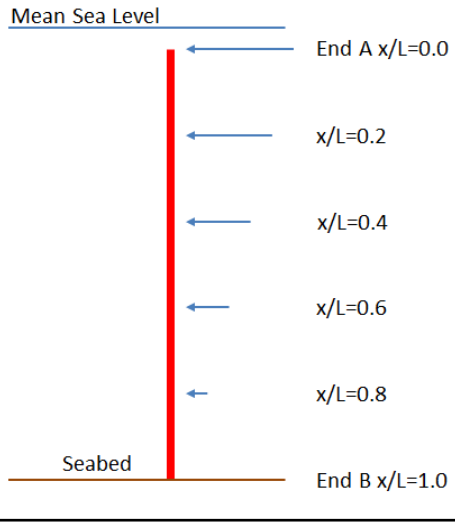


Table 8: Current Definition – Example 1 (x/L Convention Reversed)

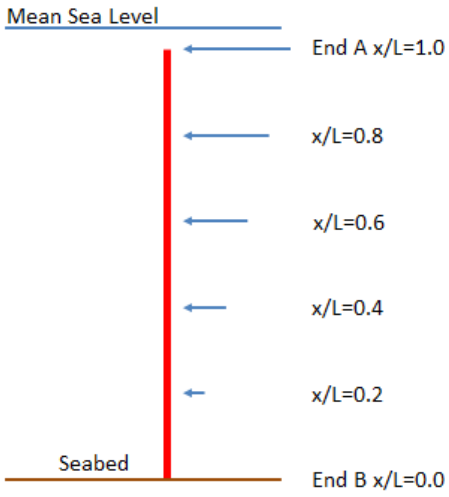
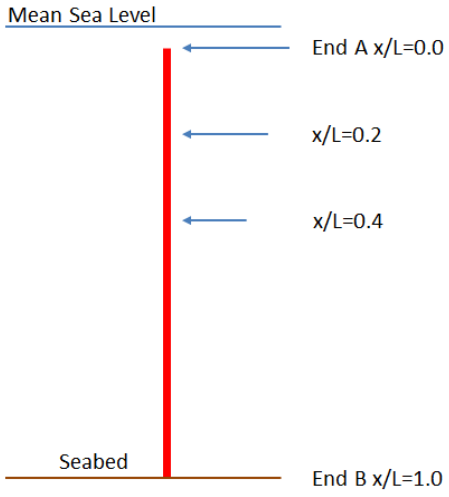
| | | | | |
|---|---|---|---|---|
| 6 | 1.0 | 1 | no. of profile data pts probability profile ID |  |
| 0.0 | 0.0 | | location (x/L) and velocity (ft/s) | |
| 0.2 | 0.2 | | location (x/L) and velocity (ft/s) | |
| 0.4 | 0.4 | | location (x/L) and velocity (ft/s) | |
| 0.6 | 0.6 | | location (x/L) and velocity (ft/s) | |
| 0.8 | 0.8 | | location (x/L) and velocity (ft/s) | |
| 1.0 | 1.0 | | location (x/L) and velocity (ft/s) | |



Table 9 presents the structure with both ends in the water and current applied to 40% of the structure length. This means that the entire structure length will account for hydrodynamic damping and added mass.

Table 9: Current Definition – Example 2

| | | | | |
|---|---|---|---|---|
| 65 | 1.0 | 2 | no. of profile data pts probability profile ID |  |
| 0.0 | 1.0 | | location (x/L) and velocity (ft/s) | |
| 0.2 | 0.8 | | location (x/L) and velocity (ft/s) | |
| 0.4 | 0.6 | | location (x/L) and velocity (ft/s) | |
| 0.4001 | 0.0 | | location (x/L) and velocity (ft/s) | |
| 1.0 | 0.0 | | location (x/L) and velocity (ft/s) | |



Sections at one or both ends are assumed to be out of water if they are left out of the velocity profile specification. All submerged regions must be specified in the velocity profile whether in still or moving water.

Table 10 presents the structure with one end out of the water and current applied to 90% of the structure length. This means that 90% of the structure length will account for hydrodynamic damping and added mass. From x/L=0 to x/L=0.1 the structure is out of the water, therefore no hydrodynamic damping or added mass is applied to this section.

Table 10: Current Definition – Example 3

| | | | |
|---|---|---|---|
| 6 | 1.0 | 3 | no. of profile data pts probability profile ID |
| 0.1 | 1.2 | | location (x/L) and velocity (ft/s) |
| 0.2 | 1.0 | | location (x/L) and velocity (ft/s) |
| 0.4 | 0.6 | | location (x/L) and velocity (ft/s) |
| 0.6 | 0.4 | | location (x/L) and velocity (ft/s) |
| 0.8 | 0.2 | | location (x/L) and velocity (ft/s) |
| 1.0 | 0.0 | | location (x/L) and velocity (ft/s) |

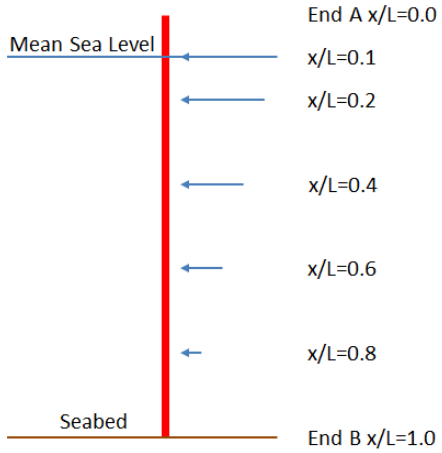
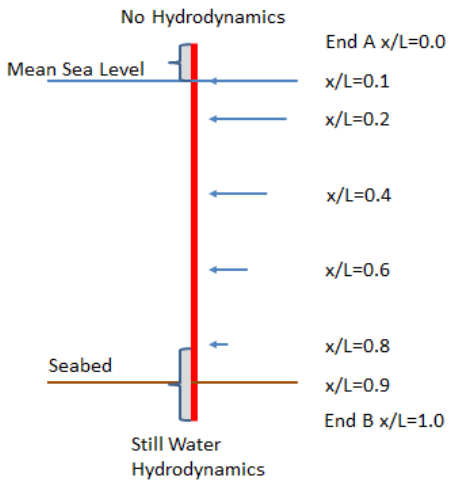


Table 11 presents the structure with one end out of the water and one end buried in the seabed with current applied to 70% of the structure length. This means that 90% of the structure length will account for hydrodynamic damping and added mass. From x/L=0 to x/L=0.1 the structure is out of the water, therefore no hydrodynamic damping or added mass is applied to this section. From x/L=0.9 to x/L=1.0 the structure is buried in the seabed. The default method for structures buried in the seabed is to specify zero current to its zone and the program will then use the still water hydrodynamic damping and added mass properties.

Table 11: Current Definition – Example 4

| | | | |
|---|---|---|---|
| 6 | 1.0 | 4 | no. of profile data pts probability profile ID |
| 0.1 | 1.2 | | location (x/L) and velocity (ft/s) |
| 0.2 | 1.0 | | location (x/L) and velocity (ft/s) |
| 0.4 | 0.6 | | location (x/L) and velocity (ft/s) |
| 0.6 | 0.4 | | location (x/L) and velocity (ft/s) |
| 0.8 | 0.2 | | location (x/L) and velocity (ft/s) |
| 0.8001 | 0.0 | | location (x/L) and velocity (ft/s) |
| 1.0 | 0.0 | | location (x/L) and velocity (ft/s) |



## 5.5 BLOCK 4 – S-N CURVE AND SCF DATA

Block 4 defines the S-N curves and SCF data to be used in the analysis.

### 5.5.1 Number Of S-N Curves

The first line of Block 4 defines the number of S-N curves included in the .s7dat file. At least one S-N curve is required for the program to run and there is no limit on the number of S-N curves that can be defined.

- Note that not all of the curves defined have to be assigned to any structural zone. This allows the user to include redundant S-N curve definitions.
- To see how multiple S-N curves are defined see the Example file “basic_beam_multi_sn” as per Table 36.

The following limitation is applied to SHEAR7 Academic Licenses:

- The number of available S-N curves is one (1)

### 5.5.2 S-N Curve Identification And Number Of S-N Curve Segments

The first number defines the S-N curve identification number. This number is used to assign the S-N curve to a given structural zone, as per Section 5.3.9.4. The first S-N curve defined must have the identification number of 1 and any further defined curves defined must be incremented by 1.

The second number specifies the number of segments defining the S-N curve. The minimum number of S-N curve segments is one, and therefore at least two S-N curve data points (with coordinates of stress range and cycles to failure as defined later in Block 4) are needed to specify each S-N Curve line segment. The maximum number of segments for a given S-N curve segments is 10.

The following limitation is applied to SHEAR7 Academic Licenses:

- The S-N curve can only have one (1) slope

### 5.5.3 Cutoff Stress Range

This defines the stress range value on the S-N curve where the number of cycles to failure is infinite. This is sometimes called the endurance limit.

### 5.5.4 Stress Range And Cycles To Failure

The first number is the stress range and the second is the number of cycles to failure corresponding to this stress range. It should be noted that for a single segment S-N curve there are two S-N pairs required. For two segment S-N curves it is required to have three S-N pairs, etc. On a log-log plot the S-N curve is assumed to be linear between these points. The stress range for the different points must be in increasing order.

### 5.5.5 Global Stress Concentration Factor

This line defines the following three factors, in order:

- Global stress concentration factor – This defines the stress concentration factor to be applied to the entire structure. The RMS stress computed by SHEAR7 for the entire structure is multiplied by this value before the damage rate is computed.
- Flag for Bending Stress Curvature Load Factor (BSCLF) – This defines whether the BSCLF is required or not. Two possible values can be entered in this position as follows:
  - 0 – SHEAR7 will calculate stress according to the input homogeneous pipe properties
  - 1 – SHEAR7 will use the BSCLF in stress and fatigue calculations
- Bending Stress Curvature Load Factor (BSCLF) – This defines the BSCLF to be applied to the bending stress, where it will be directly multiplied with the curvature. This approach has the advantage that bending stress can be directly calculated, rather than being a product of a number of different variables. This is explained in further detail in Section 5.5.5.1.

#### *5.5.5.1 Bending Stress Curvature Load Factor*

SHEAR7 includes the option to use a Bending Stress Curvature Load Factor (BSCLF) directly in stress and fatigue calculations, rather than relying on the section material properties E and D. This is for users that have complex (non-homogeneous) cross sections (typically umbilicals and unbounded flexible risers) whose stress/curvature characteristics have been calculated from physical tests and/or finite element analysis or cross-section analysis tools. If the user selects the BSCLF flag, the program will read the user-defined BSCLF value which gives stress/unit curvature as per Equation 2. The user can therefore set the bending stress/curvature behavior desired, including in addition to this any required stress concentration factors. This has the advantage that the bending stress produced for any curvature can be directly calculated (rather than being a product of a number of different variables). It also allows more enhanced coupling and alignment with 3rd party riser analysis software.

**NOTE:** Stress calculated using the BSCLF will be modified by Global and Local SCF's exactly the same as stress results from the default SHEAR7 calculation as presented in Equation 1, where the stress derived from BSCLF is calculated using Equation 3.

$$Stress_{Total} = Stress_{derived\ from\ BSCLF} \cdot SCF_{Global\ or\ Local} \qquad \text{Equation 1}$$

$$BSCLF = \frac{Stress}{Curvature} \qquad \text{Equation 2}$$

$$Stress_{derived\ from\ BSCLF} = BSCLF \cdot Curvature \qquad \text{Equation 3}$$

### 5.5.6 Number Of Local Stress Concentration Factors

This line defines the number of local SCFs to be applied to the structure. It should be noted that in the case where local SCF values are defined, those local SCF values OVERRIDE the global SCF value.

The following limitation is applied to SHEAR7 Academic Licenses:

- The number of allowable local Stress Concentration Factors (SCFs) is one (1)

#### *5.5.6.1 X/L Location And Local Stress Concentration Factor*

These values are only required if the user is defining local SCFs.

The first number is the location in x/L along the structure where the local SCF will be applied and the second is the local SCF to be applied.

- The local SCF is applied at node locations only, therefore if the x/L location of the local SCF provided is not a node location, SHEAR7 will move the local SCF of the specified location to the nearest node.

Table 12 presents the definition of the global and local SCF for an example structure, the global SCF of 2.0 will be applied to the all the nodes with exception of Nodes 10, 11, 12 and 13 (assuming even node spacing of 0.01 m), where the local SCF of 3.0 will be applied.

Table 12: Local SCF Example

| | | | | |
|---|---|---|---|---|
| 2.0 | 0 | 1.00 | | global scf, flag for bs-curv factor, bs-curv loading factor |
| 4 | | | | no. of local stress concentration positions |
| 0.10 | 3.0 | | | Node 10 |
| 0.11 | 3.0 | | | Node 11 |
| 0.12 | 3.0 | | | Node 12 |
| 0.13 | 3.0 | | | Node 13 |

## 5.6 BLOCK 5 – COMPUTATION/OUTPUT OPTIONS

Block 5 defines how SHEAR7 will calculate VIV and defines the output options written at the end of the analysis.

The default set of parameters are presented in Appendix A.

Table 13: Block 5

| | | | |
|---|---|---|---|
| *** BLOCK 5. computation/output option *** | | | |
| 3 | Mymodes | | calculation option (0,1,2 or 3) |
| 0.0000 | 1.0000 | 0.1000 | locations for output summary |
| 0.0 | | | gravitational acceleration |
| 0.05 | 0.65 | | power cutoff, primary zone amplitude limit |
| 1.0 | | | power value exponent (0 - equal probabilities;1 - power ratio) |
| 3.33 | 0.4 | | Higher harmonics factor, Higher harmonics threshold |
| 0.5 | | | Traveling wave excitation ratio |
| 4 | | | Beta control number (0 = no beta iterations, up to 10 for the number of beta iterations) |
| 0 | | | flag for selecting the riser diameter for fatigue (0=OD, 1=ID) |
| 84 | | | Reference diameter for $A_f^*$ calculation |
| 0 | | | flag for importing nodal effective tension and mass, (1=y;0=n) |
| 0 | | | flag for MATLAB animation data output, (1=yes;0=no) |
| 0 | | | flag for generating *.s7log file, (1=y;0=n) |
| 0 | | | flag for generating *.s7dmg file, (1=y;0=n) |
| 0 | | | flag for generating *.s7fat file, (1=y;0=n) |
| 0 | | | *.s7out file selection, (0=*.s7out, 1=*.s7out1, 2=*.s7out1+*.s7out2) |
| 0 | | | flag for calculating fatigue with zero-crossing method (1=y;0=n) |
| 0 | | | flag for calculating first mode in-line fatigue damage (1=y;0=n) |
| 0 | | | flag for generating *.s7str file, (1=y;0=n) |
| 1 | | | Flag for non-orthogonal damping (1=y;0=n) |
| 0 | | | flag for unique named lift table file |
| 1 | 0.01 | | flag for stick-slip hysteresis, (0=n,1=y, 2=y(unique name)) |
| 1 | | | flag for generating *.curv file, , (0=n,1=y) |
| 1 | | | flag for generating *.zeta-hyst file, (0=n,1=y) |

### 5.6.1 Calculation Option

Defines whether SHEAR7 will compute or import the natural frequencies and mode shapes of the structure. The following options are available:

- Option 0 – It will result in the natural frequencies and modes shapes being computed by SHEAR7 and put in a **root-name.s7mds** file. The VIV response or fatigue damage rate **is not** calculated when this option is selected.
- Option 1 – For simplistic structures (See Section 5.3.1) SHEAR7 will calculate structural natural frequencies and mode shapes (saved as **root-name.s7mds**) and then perform VIV analysis.
- Option 2 Uses externally prepared structural natural frequencies and mode shapes placed in a file called **common.s7mds**. The VIV response is then calculated. The external prepared structural natural frequencies are required to be "wet" natural frequencies.
- Option 3 uses externally prepared structural natural frequencies and mode shapes and allows the user selection of any name for a .s7mds file. The root of the filename, minus the .mds suffix, must be specified after selection of calculation Option 3. In the example above, the file Mymodes.s7mds will be called by the program. The VIV response is then calculated. The externally prepared structural natural frequencies are required to be "wet" natural frequencies.

Instructions on how to prepare the **common.s7mds** file for Option 2 and 3 are presented in Section 7.3. It should be noted that if Option 2 or Option 3 are used, SHEAR7 does not use all the input lines specified in Block 2. A list of the SHEAR7 used inputs relied upon for calculation Option 2 and 3 is presented in Table 14.

When using calculation Option 2 and 3, SHEAR7 will use all the modes in the .s7mds file for the mode superposition. This allows users to easily change the number of superposition modes by simply changing the number of modes in the .s7mds file.

#### *5.6.1.1 Required Inputs For The Available Calculation Options*

It should be noted that when Option 2 or Option 3 are used, SHEAR7 does not use all the input data specified in Block 2, as some of these values are used with Option 1 for the purpose of calculating natural frequencies and mode shapes. However, it is still required to have values on those fields, otherwise SHEAR7 will stop the program and return an error for incomplete input data.

A list of the SHEAR7 used inputs for calculation Option 2 and 3 is presented in Table 14.

Table 14: Required Inputs In Block 2 For Calculation Options 2 And 3

| Input | Used | Comment |
|---|---|---|
| flag for structural model | No | Any number can be entered in this field |
| total length of the structure | Yes | |
| number of spatial segments | Yes | |
| volume weight of the fluid | Yes | |
| kinematic viscosity of the fluid | Yes | |
| structural damping coefficient | Yes | |
| effective tension at origin | No | If "0" or an inaccurate tension is input, SHEAR7 may return a warning in the *.s7out file for "*Negative Tension*" |
| N° of zones to define sectional property | Yes | |
| zone start and end point in x/L | Yes | |
| Hydrodynamic diameter | Yes | |
| Strength outer diameter | Yes | |
| Strength inner diameter | Yes | |
| Inertia | No | Only used for check of beam or cable behaviour. Not required for VIV response. |
| Mass Length | Yes | Used in a modal mass calculation. |
| Submerged Weight/Length | No | |
| Modulus of elasticity | Yes | |
| SN Curve I.D. No. | Yes | |
| dVR | Yes | |
| Strouhal number | Yes | |
| Cl reduction factor | Yes | |
| CL Table N° | Yes | |
| Added Mass | Yes | |
| Damping for Reynolds number dependent still water | Yes | |
| Damping for A/D dependent still water | Yes | |
| Damping for low reduced velocity regions | Yes | |
| Damping for high reduced velocity regions | Yes | |
| Damping for axial flow regions | Yes | |

### 5.6.2 Locations For Output Summary

This line defines the response locations at which a summary of the response is given in Section 14 of the .s7*out* file. It should be noted that this is meant for summary information only and it is not necessary to use a very fine spacing here. This line has three numbers corresponding to:

- Start x/L – This defines the start point, in x/L, where the summary response in the .s7out file will start from. It does not need to be 0.
- End x/L – This defines the end point, in x/L, where the summary response in the .s7out file will end. It does not need to be 1.
- Increment x/L – This defines the segmentation, in x/L, that the summary result in the .s7out file will be presented.

It should be noted that the location for output summary does not affect the .s7plt file which gives the output at all node points.

### 5.6.3 Acceleration Of Gravity (for Tilt Contamination Estimation)

This line defines the acceleration value for gravity and is only applicable for **vertical** risers i.e drilling riser and TTR. When doing comparisons to instrumented risers, where the acceleration values are recorded. Two possible values can be entered in this line as follows:

- If 0 is entered in this line then gravity is not included in the estimate of the RMS acceleration.
- If equal to the acceleration of gravity then the predicted RMS acceleration will include the effect of tilt at each point on the riser.

This feature is implemented in structural models (nmodels) 1 and 10 only, the beam or cable with linearly varying tension. For all other nmodels the mode slope calculated in the .mds file will be zero.

### 5.6.4 Power Ratio Cutoff Level And Primary Zone Amplitude Limit

This line defines how many modes will be included in the VIV response and the distance within excitation zones that is required to have independent and simultaneous excitation zones.

#### *5.6.4.1 Power Ratio Cutoff Level*

The power cutoff level controls how many discrete modal power-in regions exist. In the program, the maximum input power and the corresponding mode is first identified. The input power level for each potentially excited mode is then divided by the maximum input power, resulting in a ratio of each mode's estimated input power to the maximum input power found for all modes evaluated. If this ratio for a particular mode is less than the cutoff value, this frequency will be excluded in the final response calculation.

The cutoff level is a number, which should always be positive and less than or equal to 1.0. When this number is very small, nearly all modal frequencies, potentially excited, will be identified and used in the response calculation. When set to 1.0, only the mode with the maximum available input power from the fluid will be included in the response calculation; in effect forcing the program to a single frequency lock-in calculation.

The higher the cutoff level, the fewer the modes remaining in the analysis. Fewer modes, means that less smoothing will occur in the RMS predicted response over the length of the riser. A cutoff of

1.0 will result in a single frequency computation. The RMS response and fatigue damage rate will typically have pronounced peaks and zeros corresponding to the absolute value of the mode shape. This has been found to not correspond to real data. Real measurements show some smoothing of the peaks, which suggests several frequencies participating in the response.

**NOTE:** In SHEAR7, the in-line fatigue calculation flag will result in the power cutoff being set to 1.0, which is the default value for in-line calculations, regardless of the user entry in the *.s7*dat file.

### *5.6.4.2 Primary Zone Amplitude Limit (PZAL)*

In addition to the occurrence of time-sharing, it is recognized that those modes that have well separated power-in regions may be able to respond simultaneously. This is because waves created in one power-in region attenuate as they travel along the structure. If two power-in regions are sufficiently far apart, the dynamic response generated in one will not be large enough to affect the excitation and vortex shedding in the power-in region of the other. In such instances, they could both be allowed to occur at the same time.

When the dynamic response from the power-in region of the dominant mode drops below a user selected limit, then it is assumed that the dynamic response is no longer large enough to disrupt the formation of a new power-in region at a different frequency. The dominant VIV freq/mode is automatically assigned to the primary zone, the response amplitude of this mode is computed everywhere along the structure's length and it is therefore straightforward to compute attenuation everywhere. The attenuation amount corresponding to the locations of the power-in regions of all other potentially excited VIV freqs/modes is then easily computed. Any VIV freqs/modes that have power-in regions sufficiently far away from the dominant mode's power-in region are assigned to secondary excitation regions that act at the same time as the VIV/freqs modes that were assigned to the primary excitation region.

This user-specified value for this amplitude limit must have a value between 0 and 1.0. The new default value is 0.65. The larger the value, the closer the secondary zones will be to the primary zone, and the more likely that the potentially excited VIV modes/freqs other than the dominant one will be allowed to exist at the same time as the modes in the primary region. Hence, higher limits should estimate greater response than lower limits. This is a subject of current research, and analysis of field measurements on drilling risers and flexible cylinders tested in model basins suggest that this value should be approximately 0.65. Which is to say that when the dynamic response from the dominant mode excitation region decays to 65% of its initial amplitude value, one has entered a secondary zone in which VIV at a different frequency is allowed to exist simultaneously.

Three time sharing scenarios are possible:

- One independent excitation zone – This happens when the amplitude of the dominant mode is greater than the limit (i.e. PZAL) set in the .s7dat file everywhere on the riser.
- Two independent excitation zones – This happens whenever the amplitude of the dynamic response from the dominant mode is smaller than the limit on only one side of the dominant power-in zone;

- Three independent excitation zones – This happens when there are secondary zones on both sides of the primary time-sharing zone.

Figure 8 presents the possible excitation zones combinations within SHEAR7.

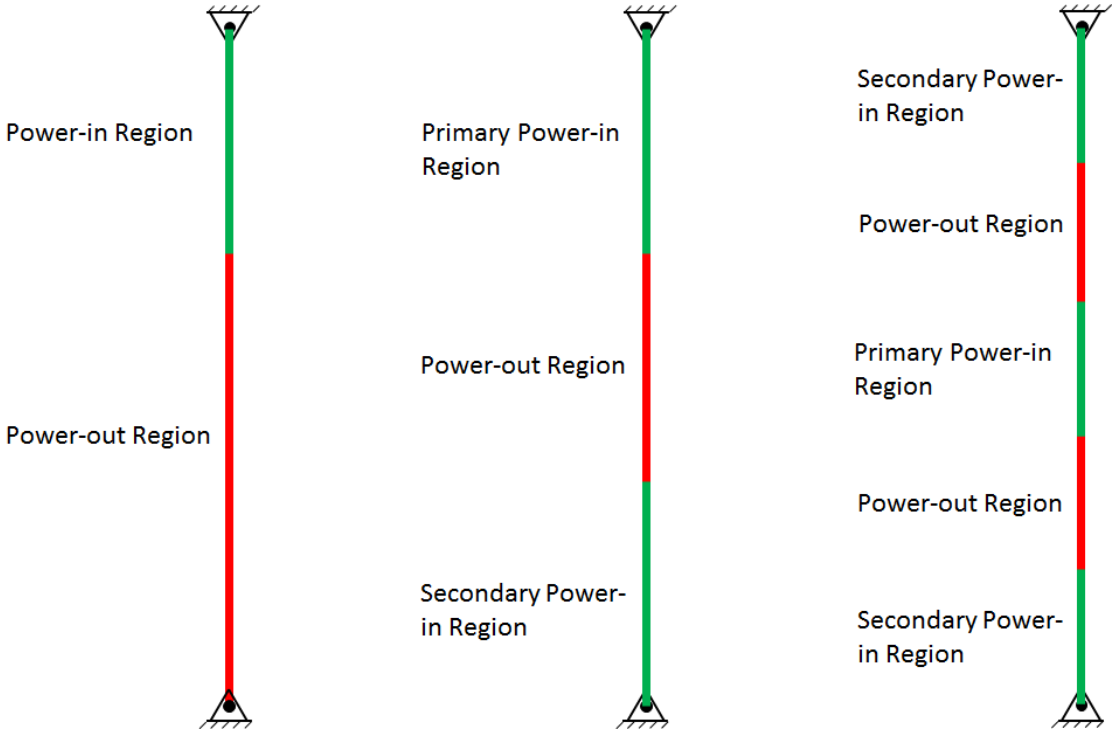



Figure 8: Possible Excitation Zones

Power-in regions for VIV freqs/modes located close to that of the dominant VIV freq/mode will be associated with structural dynamic response decay amplitudes that are close to 1.0 and will be in the primary zone. These modes will time share their probability of occurrence with the dominant VIV freq/mode.

Power-in regions located at positions on the structure where the amplitude of the dominant mode has decayed to less than the PZAL will belong to one of the two possible secondary time-sharing zones, determined by which side of the primary power-in region it falls.

After the program sorts the potentially excited VIV modes/frequencies and assigns them into the different excitation zones, the program will proceed to compute the time-sharing probabilities for all the VIV freqs/modes in each excitation zone. The program allows for up to three excitation zones and the time-sharing probabilities for VIV freqs/modes in each of these zones must add up to 1.

Excitation regions and time-sharing probabilities are reported in section 2.2.1 of the .s7out file. In the example shown in figure 9, the program has determined that mode 16 is the dominant VIV freq/mode and it is automatically assigned to excitation zone #1. The immediately neighbouring freqs/modes 12,13,14,15 & 17,18 are also assigned to the primary excitation region because the dominant mode's amplitude has not decayed by a sufficient amount (here 0.65) by the time it

reaches the location of those power-in regions. All these freqs/modes will time-share with the dominant VIV freq/mode #16 in the primary excitation region and the time-sharing probabilities will add up to 1. In this particular example, the program has determined that VIV freqs/mode 10 & 11 have power in regions that are sufficiently far away from the dominant VIV freq/mode and are thus assigned to their own secondary excitation region. VIV freqs/modes assigned in each of the two secondary regions will have time sharing probabilities that add up to 1 in their corresponding excitation region and will act at the same time with the VIV freqs/mode that are time-sharing in the primary excitation region and the other secondary excitation region if it exists.

```
 2.2.1 Results of the Mode Interaction Analysis:

Based on the non-zero power-in lengths and the power cutoff value of: 0.20
 the number of modes above cutoff is:           9
 These modes are: Time Share                     Excitation Dominant Mode
                Probabilities:                      Zone #    Amplitude:
        10           0.3505                           3       0.5830E+00
        11           0.6495                           3       0.6439E+00
        12           0.0904                           1       0.7118E+00
        13           0.1227                           1       0.7875E+00
        14           0.1676                           1       0.8742E+00
        15           0.1740                           1       0.9581E+00
        16           0.1922                           1       0.1000E+01
        17           0.1596                           1       0.9573E+00
        18           0.0933                           1       0.9156E+00
                    --------                                   --------
 Cumulative sum:    2.0000     Primary zone amplitude limit:  0.6500
 Lowest And Highest Excited Mode Number
 Nmmin=  10     Nmmax=  18
```

Figure 9: Results of the mode interaction analysis as reported in the .s7out file

Whether the secondary region is numbered as excitation zone #2 or excitation #3 is related to whether it is physically located before or after the primary excitation region. Thus the numbering depends on the user's choice of origin when defining the structure's geometry in the .s7dat input file.

Assigned excitation zones, time-sharing probabilities also appear in the .s7fat and .s7str output files.

### 5.6.5 Power Ratio Exponent

This line defines the time sharing probability when multiple modes are predicted to be excited. Two possible values can be entered in this line as follows:

- 1 – the power ranking ratios for the time sharing probabilities are equal to the ratio of modal power to maximum modal power.

- 0 – all the power ranking ratios for the time share probabilities are set to 1.0. This means that equal mode time sharing probabilities will be assigned to each of the possible excited modes for that excitation zone.

Further parametric investigation can be carried out by examining the effect of the power ratio exponent.

### 5.6.6 Higher Harmonics Correction Amplification Factor And Threshold

The first value in this line defines the Higher Harmonics Amplification Factor. The second value represents the Higher Harmonics threshold, above which a Higher Harmonics Amplification Factor gets applied.

The two parameters get applied in the code as per Equation 4 for each resonance modal response separately:

$$\text{If} \quad A^*_{rms} > A^*_{threshold,rms}$$
$$\sigma_{hh,rms} = \sigma_{rms}\left[\,1 + \alpha\left(A^*_{rms} - A^*_{threshold,rms}\right)\right] \qquad \text{Equation 4}$$

where, $\sigma_{hh,\,rms}$ is the modal RMS stress after the Higher Harmonic correction; and $\sigma_{rms}$ is modal RMS stress before the Higher Harmonic correction.

- *Where:*
  - $A^*_{threshold,rms}$ is the Higher Harmonic $A^*_{rms}$ threshold (where $A^*_{rms}$ is the RMS A/D response of each resonant mode), above which a Higher Harmonics Amplification Factor gets applied.
  - $\alpha$ is the Higher Harmonic Amplification Factor.

To run the program without activating the Higher Harmonic correction the Higher Harmonics Amplification Factor, $\alpha$, should be set to zero (0).

### 5.6.7 Traveling Wave Excitation Ratio

SHEAR7 does not necessarily force the excitation to be either purely standing wave or purely traveling wave. Instead, users can specify a traveling wave excitation ratio between 0 and 1, allowing responses to be represented as any combination of the two excitation mechanisms. This provides a more realistic framework for matching observed behavior and benchmarking against experimental data which has shown that both standing and traveling wave behavior is observed inside the power-in regions.

It is important to note that enabling the ‘traveling wave excitation’ essentially creates a lift force distribution that matches the riser/cable response inside the power-in region. This means that even with the traveling wave excitation ratio set to 1.0, there will be a few situations that the lift force distribution will continue looking like a standing wave.

To summarize, even with the ‘traveling wave excitation ratio’ set to 1.0, the typical response observed is as follows:

- a nearly standing wave like excitation will be seen in very low mode number cases or on bare cylinders in uniform current profiles
- traveling wave like excitation will be seen in moderate or high mode number cases in sheared currents or partially straked cases.

From a user perspective, the implementation is intentionally simple. The .s7dat input file contains a 'traveling wave excitation ratio' parameter. Values are chosen as follows:

- 0.0 produces a traditional standing wave excitation solution (similar to v4.12c and earlier).
- 1.0 produces a fully traveling wave excitation solution.
- Values between 0 and 1 blend the two excitation models, with the results from each excitation being 'time-shared' according to the value set by the user.
- The default value supplied in example files with the program is 0.5. This is based on preliminary benchmarking showing a good match to experimental observations.

If a traveling wave excitation ratio greater than 0.0 is used, non-orthogonal damping should be enabled (Section 5.6.20) and the beta control number (Section 5.6.8) should be set to a non-zero value.

In the very rare situations that the traveling wave excitation solution is numerically unstable and cannot converge, the program will error out and warn the user. Setting the traveling wave excitation ratio to 0.0 will revert to a pure standing wave excitation for the final calculation results, bypassing this error if necessary.

More information on this feature can be found at *Appendix L - Traveling Wave Excitation*.

### 5.6.8 Beta Iterations Control Number

This value specifies the upper limit on the number of iterations that SHEAR7 will use to calculate *beta (the ratio of total amplitude to modal amplitude)*. These are known as beta iterations. For no beta iterations to occur the value in this line should be set to zero. The possible values that can be entered in this line are as follows:

- 0 – SHEAR7 **will not** complete any beta iterations. This will predict the same response as SHEAR7 4.7c.
- 1 – SHEAR7 **will** complete one beta iteration.
- N; Up to N = 10 – SHEAR7 **will** complete a minimum of one beta iteration and a maximum of N beta iterations. The iterations will terminate prior to the maximum number of iterations if the difference from the previous iteration global beta value is less than an internally specified tolerance of 5E-02.

If the program does not reach convergence within the specified limit it is suggested that the user increases the beta control number (up to the limit).

Users are advised that the program does not provide any inbuilt checks to ensure that beta is converging. If beta does not converge, the program will run to the maximum number (N) of beta iterations before proceeding with the solution.

Please note that increasing the number of beta iterations will generally result in a less conservative prediction.

### 5.6.9 Fatigue Calculation Diameter Flag

Flag to specify whether the outer or inner diameter(s) which should be used for calculating the fatigue. If multiple zones are present, SHEAR7 will use the same diameter flag for each of the zones. Two possible values can be entered on this line as follows:

- 0 – SHEAR7 will use the **outer diameter** specified in each zone for calculating fatigue.
- 1 – SHEAR7 will use the **inner diameter** specified in each zone for calculating fatigue.

### 5.6.10 Reference Diameter For A* Calculation

The diameter provided on this line is used in calculating the non-dimensional parameters A* and c*. If the diameter is specified appropriately, the product of A* and c* represents the lift coefficient of the riser. The units for the reference diameter are as per Table 1. Please note, the parameters of A* and c* are part of ongoing research.

### 5.6.11 Import Common.s7cat

As of v4.11, there are two reasons to import a *.s7cat file:

1) For importing the tension distribution to assist in the calculation of the varying structural damping “stick-slip” module.

2) For assisting in the calculation of natural frequencies and modeshapes when using the internal SHEAR7 structural engine to compute these. Most commonly this would be needed for catenary shapes.

The **common.s7cat** file is not generally required when importing natural frequencies and mode shapes which is the most usual approach users take when modeling structures.

This line defines whether the **common.s7cat** is required for the VIV analysis. The **common.s7cat** file contains the tension variation and the mass per unit length distribution of the structure and is used to compute the modal response of a non vertical riser. Three possible values can be entered in this line as follows:

- 0 – common.s7cat **is not** required for the analysis.
- 1 – common.s7cat **is** required for the analysis.
- 2 - <unique-name>.s7cat **is** required for the analysis.

When using Option 2 in the .s7dat file, type the option number, followed by a single space and then the title of the <unique-name>.s7cat file name (minus the ***.s7cat*** suffix)

#### *5.6.11.1 Common.s7cat Specification*

The **common.s7cat** input data file contains externally provided tension and mass per unit length data for each node. The number of nodes specified in the **common.s7cat** file must be one greater than the number of spatial segments (section 5.3.3) in the input .s7dat file. There are four (4) columns required in the common.s7cat file:

- Column 1: Node Number
- Column 2: Tension Variation
- Column 3: Mass per Unit Length
- Column 4: Mean Curvature

An excerpt from the **common.s7cat** file, provided to run example file **scr_import_tension.*s7*dat,** is presented in Table 15.

Table 15: Common.s7cat Example

| | | | |
|---|---|---|---|
| 1 | 16560 | 3.49485 | 0 |
| 2 | 17252.16992 | 3.49485 | 0.001 |
| 3 | 19644.23828 | 3.49485 | 0.0015 |
| 4 | 25114.49805 | 3.49485 | 0.002 |
| 5 | 18115.56055 | 3.49485 | 0.0025 |
| … | … | … | … |
| 199 | 94672.63281 | 3.49485 | 0.003 |
| 200 | 95140.54688 | 3.49485 | 0.0031 |
| 201 | 95613.125 | 3.49485 | 0.0032 |

### 5.6.12 Flag For MATLAB Animation File

The MATLAB animation files allow animations at single frequencies at a time or with a superposition of two or more excited nodes. Animations using multiple simultaneous frequencies are appropriate when the frequencies are selected from the primary and secondary response zones.

For creation of the animation *.s7anm* file. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 **will not** report the *.s7anm* file
- 1 – SHEAR7 **will** report the *.s7anm* file

Further description about each output file is presented in Section 7.

### 5.6.13 Flag For .s7log File

In normal execution of the program, it is not recommended to produce the .s7log file. The *.s7log* file generated by SHEAR7 is intended to reveal at what point the program has execution problems and help the users to estimate where the problem occurs. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 **will not** report the *.s7log* file
- 1 – SHEAR7 **will** report the *.s7log* file

Further description about each output file is presented in Section 7.

### 5.6.14 Flag For .s7dmg File

The *.s7dmg* file generated by SHEAR7 reports the Rayleigh fatigue damage rate per year results for all resonant mode numbers at each node. This fatigue damage rate has not been multiplied by the time sharing probability. When the zero crossing fatigue calculation is used it reports the fatigue damage rate and its respective zero crossing frequency. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 **will not** report the *.s7dmg* file
- 1 – SHEAR7 **will** report the *.s7dmg* file

Further description about each output file is presented in Section 7.

### 5.6.15 Flag For .s7fat File

The *.s7fat* file generated by SHEAR7 reports the total response amplitude and phase angle at every node for every response frequency. Combining this with mode shape information allows one to reconstruct times series of stress at every node for time domain fatigue damage computation purposes. The need to use this file has largely been superseded with the *.s7*str file. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 **will not** report the *.s7fat* file
- 1 – SHEAR7 **will** report the *.s7fat* file

Further description about each output file is presented in Section 7.

### 5.6.16 Flag For .s7out Or .s7out1 And .s7out2 Files

The .s7*out* file is always created and reproduces the input data and summarizes the analysis results from the SHEAR7 program. Specific sections of the .s7*out* file can be extracted to the .s7*out1* and .s7*out2* files if requested.

The .s7*out1* file include the listings of the lift coefficient, the non-dimensional frequency and the reduced velocity in the power-in zones. The content of this file is identical to section 14 of the .s7*out* file .See Section 7.8 for further description of the .s7*out1* file.

See Section 7.9 for description of the .s7*out2* file.

Three possible values can be entered in this line as follows:

- 0 – SHEAR7 will report the *.s7out* file
- 1 – SHEAR7 will report the *.s7out* and *.s7out1* files
- 2 – SHEAR7 will report the *.s7out*, *.s7out1* and *.s7out2* files

Further description about each output file is presented in Section 7.

### 5.6.17 Flag For Zero Crossing Frequency Fatigue Calculation

Flag for calculating fatigue using the zero-crossing method. (0 = No, 1=Yes). If zero-crossing is selected, then $S_{rms}$ is calculated as for the default calculation, and fatigue damage is calculated using $S_{rms}$ and an equivalent zero crossing frequency from all resonant modes' natural frequencies. Selecting 0 for this option results in the default SHEAR7 fatigue damage calculation used in all previous versions of SHEAR7.

The zero crossing fatigue calculation option allows users to select a zero crossing frequency approach to calculate fatigue damage, and outputs additional information that can be used for alternate fatigue calculations.

In the default SHEAR7 fatigue calculation in the presence of time-sharing modes, damage is directly calculated from a sum of individual resonant modes, $Sr_{rms}$ at resonant frequencies, weighted by time-sharing probability. In the zero crossing calculation, an equivalent zero crossing RMS stress is calculated (as before, this is the output in the .s7out and .s7plt files) and an equivalent zero crossing frequency is calculated. The damage is then directly calculated from the zero crossing RMS stress and frequency. Note, both zero crossing and default fatigue damage calculations incorporate a Rayleigh factor. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 will use the **default** fatigue calculation.
- 1 – SHEAR7 will use the **zero crossing** fatigue calculation.

### 5.6.18 Flag For Pure In-line Fatigue Calculation

Flag for calculating first mode in-line fatigue damage, (0 = No, 1=Yes). Selecting 1 results in power cutoff being set to 1.0, regardless of user input, and a message in the .s7out file that in-line fatigue damage is being calculated. Selecting 0 runs SHEAR7 for cross-flow.

### 5.6.19 Flag For *.s7str* File

The *.s7str* file generated by SHEAR7 reports the RMS stress of each resonant mode at each node for the users that have their own methodology to compute the fatigue damage rate. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 **will not** report the *.s7str* file.
- 1 – SHEAR7 **will** report the *.s7str* file.

Further description about each output file is presented in Section 7.

### 5.6.20 Flag For Non-Orthogonal Damping

Flag to account for non-orthogonal damping when calculating the VIV response. Using this flag activates a significant improvement to the modeling of spatially varying damping, resulting in a more accurate response prediction, particularly in regions outside of the excitation zone. SHEAR7 accounts for the structural damping in a way that leads to proportional damping matrices. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 will **not** model the non-orthogonal damping terms.
- 1 – SHEAR7 will model the non-orthogonal damping terms.

When using non-orthogonal damping the beta control number (Section 5.6.8) should be set to a non-zero value.

### 5.6.21 Flag For Uniquely Named Lift Table File

Defines whether SHEAR7 will use the lift table file provided in the SHEAR7 installation package, common.s7cl, or a lift table file with a unique user provided name. The following options are available:

- 0 – SHEAR7 will look for a lift table file titled **common.s7cl**.
- 1 – SHEAR7 will look for a uniquely named lift table file **unique-name.**s7**cl**.

When using Option 1 in the .s7dat file, type the option number, followed by a single space and then the title of the <unique-name>.s7cl file name (minus the **.s7*cl*** suffix)

Option 0 is the default option.

### 5.6.22 Flag For Stick-Slip Hysteresis

Flag to account for damping from stick-slip hysteresis when calculating the VIV response. Three possible values can be entered in this line as follows:

- Option 0 – SHEAR7 **will not** model stick-slip hysteresis.
- Option 1 – SHEAR7 **will** model stick-slip hysteresis and the hysteresis curves are specified in a file called **rootname.s7inhyst**, where *rootname* is the name of the .s7dat file.
- Option 2 – SHEAR7 **will** model stick-slip hysteresis and the hysteresis curves are specified in a user defined .s7inhyst file.

If stick-slip hysteresis is modelled, the user must also specify a tolerance of convergence. The iteration convergence tolerance is calculated as the percentage change of the stick-slip damping coefficient. This value must be provided after the stick-slip hysteresis flag. Stick-slip hysteresis flag options are defined in Table 16.

Table 16: Stick-Slip Hysteresis Flag Examples

| | | | | |
|---|---|---|---|---|
| OPTION 0: | 0 | | | flag for stick-slip hysteresis |
| OPTION 1: | 1 | 0.001 | | flag for stick-slip hysteresis, tolerance of convergence |
| OPTION 2: | 2 | 0.001 | myhyst | flag for stick-slip hysteresis, tolerance of convergence |

### 5.6.23 Flag For Generating *.s7curv File

Flag to generate output file from the Varying Structural Damping module. The *.s7curv file is a new output file that will only be generated if the flag for stick-slip hysteresis is also flagged. The following options are available:

- 0 – SHEAR7 **will not** generate the *.s7curv file.
- 1 – SHEAR7 **will** generate the *.s7curv file.

The *.s7curv file will be named as per the input *.s7dat file naming.

Option 0 is the default option.

### 5.6.24 Flag For Generating *.s7zeta-hyst File

Flag to generate output file from the Varying Structural Damping module. The .s7zeta-hyst file generated by SHEAR7 reports the stick-slip damping ratio for a range of tensions and curvatures. The following options are available:

- 0 – SHEAR7 **will not** generate the *.s7zeta-hyst file
- 1 – SHEAR7 **will** generate the *.s7zeta-hyst file

The *.s7zeta-hyst file will be named as per the input *.s7dat file naming.

Option 0 is the default option.

## 5.7 BLOCK 6 – SUPPLEMENTAL DATA

For simplistic structures (see Section 5.3.1) where the user selects to have SHEAR7 calculate structural natural frequencies and mode shapes there may be supplemented data required. Several structural models internal to SHEAR7 that when assigned in Block 2 require additional data. Most of them are cases with rotational or translational springs attached at one of the ends of the riser. When one of these "nmodels", 6, 9, 19, or 33 are specified in Block 2, Line 1, then one or more additional data lines are inserted immediately after the Block 6 Header.

Table 17: Supplemental Data Example

| | |
|---|---|
| *** BLOCK 6. supplemental data *** | |
| 0.10E+07 | Rotational stiffness at x/L=1 lbf-ft/rad |
| 0.10E+07 | Rotational stiffness at x/L=0 lbf-ft/rad |

The two lines as shown in Table 17 are rotational spring constants as used in example basic_beam_3.*s7*dat which is a beam with rotational springs at the ends.

It should be noted that any text written after the last item of data expected by the program will be ignored. Hence the following lines are placed in many of the sample .*s7*dat files.

if nmodel = 6 (pinned-pinned tensioned beam w/two rot springs)
provide rotational stiffness at each end
if nmodel = 9 (free-pinned (w/spring) beam w/varying tension, origin at free end)
provide translational stiffness at x = L
if nmodel = 19 (free-pinned (w/spring) beam w/o tension, origin at free end)
provide translational stiffness at x = L
if nmodel = 33 (inclined cable)
provide chord inclination (angle)

## 5.8 BLOCK 7 – TIME HISTORY DATA

SHEAR7 now includes an optional stress, displacement and curvature time history output option. The output is stress versus time, displacement versus time and curvature versus time for each node in the modeled structure. This information can be post-processed into a loading histogram, for inclusion in external fatigue calculations. Calculation of time histories does not include the conservative Rayleigh assumption.

Note that enabling calculation of fatigue using the zero-crossing method alongside outputting of time histories is currently not supported and will cause Shear7 to exit early with a warning.

The time history input data is defined in Block 7, a new block added to the .s7dat file in v4.11. The whole block is optional so the .s7dat file does not need to have a Block 7. If the .s7dat file does have a Block 7, it must have the first line which is just a 0 or 1; 0 for no time history output, 1 for all time history outputs (.s7sth, s7dth, s7cth for stress, displacement and curvature time histories, respectively). If the first line of Block 7 has option 1 selected, but no other parameters defined, SHEAR7 will generate the output using the default values.

A set of example input parameters are presented in Table 18. An example input file is provided with the program. Variables can be capitalized or in lower case. Spaces are not allowed between the data on the one line.

Table 18: Block 7

| | |
|---|---|
| *** BLOCK 7. time history data *** | |
| 1 | flag for time history output, (1=y, 0=n) |
| TOTAL=3600.0 | total time in sec, (optional) |
| SAMPLE=1.0 | sample period in sec, (optional) |
| NODES=1:5,251,1884 | output node ranges, (optional) |
| SEED=123 | random number seed, (optional) |
| Notes:<br>1. Block 7 is the only block in the .s7dat file which requires characters before the input value.<br>2. Order of inputs does not matter, but all inputs must be on separate lines.<br>3. If any or all inputs are missing the default values will be used. | |

Each of the lines that start with a variable name are optional. The order is also not important. If any are not provided, a default is used.

- Default TOTAL time ensures there are at least 10 periods for the mode with the longest period.
- Default SAMPLE time ensures at least 10 samples per period for the mode with the shortest period.
- Default NODES outputs the results for all nodes. This comes with a warning saying that this could result in a very large .s7sth file.
- Default SEED is a random number.

The NODES are the nodes to calculate and output the time histories. This can be specified as a series of nodes separated by commas (with no spaces). They can also be specified as ranges so 1:5 would be the same as 1,2,3,4,5.

For each repeat period the order of the frequencies gets randomly allocated. A seed number can be specified to ensure the ordering is repeatable.

Each mode/frequency is split into the traveling wave excitation results followed by the standing wave excitation results, with the relative number of time steps determined by the traveling wave excitation ratio.

Modes/frequencies present from an independent excitation zone will also be present with their respective time-sharing proportions.

Appendix K shows an illustration of how time-sharing is combined into the time history.

# 6 PROGRAM OPERATION AND EXECUTION

## 6.1 PROGRAM EXECUTION OPTIONS

The SHEAR7 program has been developed in Fortran and has been compiled to run as a Windows executable file on PC's. SHEAR7 since version 4.3 will run in the command window under Microsoft Windows. There are several ways to execute the program, each is described below:

(i) Execution-Direct Method Individual File: Place the SHEAR7 executable file in the same directory as the input data files (which include the **common.s7cl** file). Double click on the executable and respond to the prompt to enter the **root-name** of the *.s7dat* file.

(ii) Execution-Direct Method Batch File: Create a batch file in the same directory of the SHEAR7 input files and save it with the *.bat* extension. On each line of the batch file insert the instruction '`shear7_5.0b.exe root-name`'. If the SHEAR7 executable file is not in the same directory with the data files, then the explicit path must be given to the SHEAR7 executable file in the batch file. Example of the batch file is provided below as well as in the SHEAR7 Example directory.

REM Example SHEAR7_batch.bat

```
shear7_5.0b.exe basic_beam_1
shear7_5.0b.exe basic_beam_2
shear7_5.0b.exe basic_beam_3
```

(iii) Execution-Specify a Shortcut to the Executable: You may also place a shortcut on the desktop and set the properties of the shortcut so that the proper paths to the executable and to the input data may be found. They may be in separate directories. The common.s7cl, **common.s7cat** and the **common.s7mds** files should be in the same directory as the **rootname.*s7*dat** files. The output files always accumulate in the same directory as the input .*s7*dat files.

Additionally third party software, such as OrcaFlex and Flexcom have capabilities to execute the programs. Check www.shear7.com for latest updates and capabilities.

## 6.2 32 AND 64 BIT SHEAR7

The default installation package only contains a 64 bit versions of the executable.

## 6.3 INPUT FILES

A set of sample data files are provided for the user's convenience. These examples demonstrate a variety of capabilities of the program, such as calculation options, VIV suppression simulation, different boundary conditions and may be used as models for similar user defined structures.

The program may use up to four user-provided input files. When the SHEAR7 program runs, it reads in data from an input data file of the form **root-name.*s7*dat**. This file is always required.

A second mandatory input data file is the lift table file. A lift table file, titled **common.s7cl**, included with the program distribution has several tables of lift coefficient. The user can add to the lift table file custom built tables of lift coefficients. This file is always required. Prior to SHEAR7 v4.11 it was required this file be titled **common.s7cl**. Now, the lift table file may be uniquely named.

When calculation Option 2 is used the program expects to find a file named **common.s7mds**. Preparation of this file is described in Section 7.3.1. When calculation Option 3 is used, the name of a user-specified *.mds* file must be included next in the *.s7dat* file (minus the *.mds* suffix). The program expects to find the *.mds* file present in the directory. This Option 3 provides better quality control over the naming and tracking of the structural files.

When the user specifies in the input data file the use of externally provided tension and mass per unit length data, as is only required under certain conditions when using Option 1, the program expects to find a file named **common.s7cat** or <unique-name>.s7cat The preparation of this file is described in the discussion of input data under Section 5.6.11.

When a user would like to make use of the Varying Structural Damping “Stick-Slip” module, refer to Appendix I .

## 6.4 COMMAND-LINE OPTIONS

SHEAR7 provides command-line options to provide additional information to the user. The available options and descriptions are provided in Table 19.

Compiler options can appear in any order, however they must all appear **after** the .*s7*dat file name.

Options cannot be combined with a single dash. For example:

- This is incorrect: -tnologo; this is correct: -t -nologo

All command-line options are case sensitive.

Table 19: Command-Line Options

| Option | Description |
|---|---|
| -nologo | The version information header is not displayed. |
| -t | Display the analysis run time in seconds. |

# 7 AVAILABLE OUTPUT FILES

SHEAR7 will normally create three output files, *.s7out*, *.s7plt*, *and .s7mds*. The *.s7mds* file will not be generated if using a user defined *.s7mds* file.

Additional, optional output files, (*.s7anm*, *.s7log*, *.s7dmg*, *.s7fat*, .s7*out1*, .s7*out2* & *.s7str*, *.s7curv*) can be created when specified by the user. See example scr1.*s7*dat and the description given later in this section. Each of the output file types is described below.

## 7.1 ROOT-NAME.S7OUT (ALWAYS CREATED)

A file which reproduces the input data and summarizes the analysis results from the SHEAR7 program.

The presentation method used below is to list the complete results of running the example case "basic_beam_3.*s7*dat". The output file "basic_beam_3.s7out" is listed below. Additional explanation is given in a bold typeface and placed at appropriate points throughout the example output file. The file begins with a notation, which includes the version number of SHEAR7 which was used to obtain the file. Immediately following is a complete listing taken from the input data file, which in this case was "basic_beam_3.*s7*dat".

**The top of the file is the SHEAR7 header logo, version information and the name of the input file that was used.**

**The first part of the file is the echo of the input file, Blocks 1 to 6 and it is presented to confirm the inputs that SHEAR7 used to compute the VIV response.**

```
   YOU HAVE INPUT:
   ===============

*** BLOCK 1. unit system ***
   flag for units:         1    English

*** BLOCK 2. structural and hydrodynamic data ***
   flag for structural model:    6
   total length of the structure (ft.):  1500.000
   number of spatial segments:  100
   volume weight of the fluid (lb/ft**3):    64.000
   kinematic viscosity of the fluid (ft**2/s): 0.1400E-04
   structural damping coefficient: 0.00300
   effective tension at origin (lbf):    224809.0
   no. of zones to define sectional property:    1

   start and end point of each zone in x/L:  0.0000    1.0000
   hydrodynamic,strength,inside diameter(in)  84.000 46.000   42.000
   inertia (ft**4) 3.2330E+00  mass (lb/ft)  2296.140  sbmg wt (lbf/ft)  1.669E+02
   elastic modulus (ksi): 0.3002E+05  SN Curve I.D. No:   1
   dVR, St code, Cl reduction factor, zoneCLtype:   0.500     0.180     1.000        1
   added mass coeff, hydrodynamic damping factors:    1.000     1.000     0.200     0.180     0.200     0.000
```

```
*** BLOCK 3. current data ***
   profile data pts:   6  probability: 0.100E+01  profile ID:     200
   location (x/L) and velocity (ft/s): 0.040    4.3000
   location (x/L) and velocity (ft/s): 0.133    4.2900
   location (x/L) and velocity (ft/s): 0.267    2.4200
   location (x/L) and velocity (ft/s): 0.500    1.4900
   location (x/L) and velocity (ft/s): 0.973    1.0100
   location (x/L) and velocity (ft/s): 1.000    1.0000

   Unspecified regions are out of water.

*** BLOCK 4. s-n and scf data ***

   no. of S-N curves defined:    1

   S-N Curve I.D. No.    1   no. of S-N curve segments:    1
   cut-off stress range for this curve (ksi):    0.0000
   stress range (ksi),cycles to failure: 0.4010E+01   0.1000E+09
   stress range (ksi),cycles to failure: 0.4700E+02   0.1000E+05

   global stress concentration factor: 1.000
   flag for bending stress curvature factor:   0   no
   no. of local stress concentration positions:    0

*** BLOCK 5. computation/output option ***
   calculation option:   1    internal modes used in analysis
   response location definition: 0.0000  1.0000  0.1000
   input gravitational acceleration (ft/s**2):  0.000
   cutoff to eliminate modes:  0.20
   primary zone amplitude limit:  0.6500
   power value exponent used:  1.0000
   higher harmonic amplification factor used:  3.3300
   higher harmonic threshold used:  0.4000
   traveling wave excitation ratio used:  0.5000
   Beta control number for Distributed beta:    4
   Diameter type (inner or outer) used for stress computation:    0   OD
   Reference diameter used for Af* and cf* computation:  84.0000 in
   flag for importing nodal tension & mass:   0   no   flag
   flag for MATLAB animation data output:     0   no
   flag for generation *.s7log file output:     0   no
   flag for generation *.s7dmg file output:     0   no
   flag for generation *.s7fat file output:     0   no
   flag for generation *.s7out file output:     0   *.s7out
   flag for calculating fatigue with zero-crossing method:    0   no
   flag for calculating first mode in-line fatigue damage:    0   no
   flag for .s7str file output:    0   no
   flag for non-orthogonal damping:    1   yes
   lift table file:    0    common.s7cl
   flag for stick-slip hysteresis:    0   no
```

```
   flag for generation *.s7curv file output:    0   no
  flag for generation *.zeta-hyst file output:    0   no

*** BLOCK 6. supplemental data ***
   rot stiffness at x=L: 1.00000E+06 lbf-ft/rad.
   rot stiffness at x=0: 1.00000E+06 lbf-ft/rad.

*** BLOCK 7. time history data ***
   flag for stress time history: 0   no

   Lift Coefficient Data

   CL Table Set No.:   1
 This CL Table used in the following sectional property zones:
  1
   Number of frequencies:  1
    ndFreq       aCL0        aCLmax       CLmax        CL0          CLfloor
    1.00000E+00   1.10000E+00   3.00000E-01   7.00000E-01   3.00000E-01  -1.00000E+00
```

**Next in every .s7*out* file comes the results of computations.**

```
   THE RESULTS OF PROGRAM ANALYSIS
   ==============================
    1. You have selected the following options:
    1.1 CALCULATING NATURAL FREQUENCY and MODE
       SHAPE and VIV response with following
       structural model:
      pinned-pinned beam (w/two rot springs) (varying tension)
    1.2  The English unit system
    1.3  The following damping factors are used:
         1   1.000   0.200   0.180   0.200   0.000
```

**Section 1 describes a few inputs for computations of the VIV response.**

```
   2. Structural dynamic behavior.
    2.1 String or beam?
      Tk^2/EIk^4 =  1.859E-01
     When the above value is less than 30
     you should use the beam model.
```

**Section 2 describes the structural behaviour.**

**Section 2.1 uses the provided E and I to compute the bending stiffness of the structure and performs a useful check on the model being used when SHEAR7 computes the modal response. When this value is greater than 30, the bending stiffness, EI, does not significantly affect the natural frequency computation. Tension is dominant and therefore the user may want to use the cable structural model because it is computationally faster. In this example EI is important, and the beam model is necessary.**

2.2 Potential frequencies in the excitation band,
frequency power/max-power, frequency participation factors:
F = force; L = length; T = time.

Power ratios are based on standing wave excitation

Standing Wave Excitation

| freq no. | freq. (Hz) | modal force magnitude (F) | modal force phase angle (radians) | modal damping (F*T/L) | modal power (F*L/T) | power ratio to max | power ratio raised to the exponent |
|---|---|---|---|---|---|---|---|
| 1 | 0.0176 | 0.000E+00 | 0.000E+00 | 0.104E+05 | 0.000E+00 | 0.00000 | 0.000E+00 |
| 2 | 0.0426 | 0.331E+04 | 0.000E+00 | 0.575E+04 | 0.987E+03 | 0.05004 | 0.500E-01 |
| 3 | 0.0789 | 0.688E+04 | 0.000E+00 | 0.139E+05 | 0.510E+04 | 0.25855 | 0.259E+00 |
| 4 | 0.1279 | 0.144E+05 | 0.000E+00 | 0.180E+05 | 0.197E+05 | 1.00000 | 0.100E+01 |

Traveling Wave Excitation

| freq no. | freq. (Hz) | modal force magnitude (F) | modal force phase angle (radians) | modal damping (F*T/L) | modal power (F*L/T) |
|---|---|---|---|---|---|
| 1 | 0.0176 | 0.000E+00 | 0.000E+00 | 0.104E+05 | 0.000E+00 |
| 2 | 0.0426 | 0.294E+04 | 0.881E-01 | 0.575E+04 | 0.796E+03 |
| 3 | 0.0789 | 0.687E+04 | -0.409E+00 | 0.139E+05 | 0.519E+04 |
| 4 | 0.1279 | 0.144E+05 | -0.165E+00 | 0.180E+05 | 0.198E+05 |

No. of potentially excited modes: 3

**Section 2.2 is a result of one of the most important steps in the program's VIV modeling. In this step the program identifies all possible excited modes within the Strouhal frequency range. In turn each one is assigned the full length power-in region, based on the reduced velocity bandwidth assigned in the input data file. Overlap with other power-in regions is ignored. Modal force, modal damping and modal power are computed. The modal power ratio is calculated as a ratio of each modal power to the maximum modal power. The last column lists the mode ranking ratios and is equal to the power ratios raised to the exponent, which is used to compute the modal time sharing probabilities. These values are computed separately for standing wave excitation and traveling wave excitation, with power ratios only computed for standing wave excitation.**

**If traveling wave excitation ratio is set to 0, traveling wave excitation calculation will be skipped and '*' outputted to the table to indicate it was not run.**

**In each zone, straked or bare, the maximum CL value, Clmax, for any lift curve selected is used to compute the modal force and the modal power for each mode. The maximum mode amplitude a/D = 0.5, the Strouhal Number and 'the maximum zone bandwidth used in the preliminary calculation' are used for that purpose.**

2.2.1 Results of the Mode Interaction Analysis:

Based on the non-zero power-in lengths, the use of standing wave excitation
power values and the power cutoff value of: 0.20
the number of modes above cutoff is: 3
These modes are: Time Share Excitation Dominant Mode
Probabilities: Zone # Amplitude:

| | | | |
|---|---|---|---|
| 3 | 0.2054 | 1 | 0.9521E+00 |
| 4 | 0.7946 | 1 | 0.1000E+01 |

Cumulative sum: 1.0000 Primary zone amplitude limit: 0.6500
Lowest And Highest Excited Mode Number
Nmmin= 3 Nmmax= 4

**Section 2.2.1 will apply the power cut off ratio to the results of Section 2.2 and presents the modes excited and their probabilities. These mode numbers are listed in Column 1. Their time sharing probabilities, excitation zone numbers, and amplitude ratios values are listed in the remaining columns.**

**The cumulative sum of the time sharing probabilities is listed at the bottom of the table. The dominant mode amplitude limit is also printed under the table for easier cross-reference with the amplitude ratios.**

**The primary time sharing modes are those, whose centers of action fall close to that of the dominant mode. In this zone the dominant mode amplitude is greater than or equal to the primary zone amplitude limit. Wherever the dominant mode amplitude is smaller than the limit value, modal power-in regions are assigned to secondary time sharing zones. Zone number 1 in Table 2.2.1 is the primary time sharing zone. Secondary zones are numbered 2 or 3. The time share probabilities in each of the independent time sharing zones add up to 1.0.**

**Time sharing modes calculation is based only on the calculated power from standing wave excitation.**

**Please note that when there are many modes above cutoff, and if the number of nodes is not large enough, some of the modes that are above cutoff may not get any input power region, and therefore they may also be dropped out. These modes are insignificant to fluid input power.**

2.3 Ratio of change of vel to average vel: 1.65
The number of excited modes and the velocity ratio together
provide insight as to the likelihood of lock-in.

**The velocity ratio in Section 2.3 is the change in velocity in the profile ($V_{max}$-$V_{min}$) divided by the spatial average velocity of the profile. Zero velocity regions are excluded from the average. This is a measure of the amount of shear in the profile. Both very large shears (greater than 1.2) and very small ones (less than 0.4) are known to provide particularly favorable conditions for single mode dominance as is the case here.**

2.4 Finite or infinite system behavior? Dominant mode amplitude exponents:

| MODE | WAVE | Dominant_m to n# | Dominant_m to n# |
|---|---|---|---|

| NUMBER # n | PROPAGATION PARAMETER n*zeta_n | DISTANCE RATIO DelX/L | MODE AMPLITUDE EXPONENT pi*zeta_m*m*\|DelX\|/L |
|---|---|---|---|
| 3 | 0.1342 | 0.1250 | 0.0491 |
| 4 | 0.1250 | 0.0000 | 0.0000 |

When the value n*zeta_n in the table is greater than 2, infinitely long structural behavior dominates. When this value is less than 0.2, spatial attenuation is small.

The dominant mode amplitude exponents listed are those used in the computations of the amplitude values listed in Table 2.2.1.

Please note, that for the dominant mode the |DelX|/L=0.0 and the mode amplitude value equals 1.0. Similarly, in uniform currents all the mode centers of action coincide, |DelX|/L=0.0 and the mode amplitude values also equal 1.0.

**n is the mode number and $\zeta_n$ (zeta_n) is the total modal damping including structural and hydrodynamic sources. The product $n \cdot \zeta_n$ (n*zeta_n) is a measure of the spatial attenuation that occurs as a wave travels along a structure. It is therefore a measure of the dynamic length of the cable, independent of the real length. A cable is "long" in a dynamic sense when waves die out before reaching the furthest end. It is "short" when very little decay occurs and the waves reflect from the ends creating a standing wave pattern from end to end.**

**The formulae used to calculate all the numbers listed in Table 2.4 are quoted in the headings of each column. $n \cdot \zeta_n$ is used to compute the amplitude ratios listed in Table 2.2.1.**

**The last column lists the exponent for computing the amplitude attenuation factor between each mode and the dominant power-in mode. The attenuation is calculated based on the center locations of the power-in regions.**

3. The ratio of the change of tension to the average tension: 0.7188
   The bigger the ratio, the larger the variation in tension.

4. Structural Properties

| zone | air mass slug/ft | mass ratio | total mass slug/ft | inertia ft**4 | steel area ft**2 | hydro area ft**2 |
|---|---|---|---|---|---|---|
| 1 | 7.138E+01 | 7.322E-01 | 1.479E+02 | 3.233E+00 | 1.920E+00 | 3.848E+01 |

In the above table, if mass ratio is zero, it means that this zone is out of water.

**Section 4. is a useful summary of the properties of a section, as computed internally using the data provided by the user. For example the inertia provided here is the area moment of inertia, I, as used to compute bending stiffness, EI. It is computed from the inside and outside diameters of the strength material for the zone. It is not necessarily the same as the I value provided by the user, which may account for other contributions such as internal tubulars. The steel area is the area defined by the strength diameters. The hydro area is the area of the cross-section with the specified hydrodynamic diameter. The total mass per unit length includes the computed added**

**mass plus the mass per unit length given in the input data file and repeated here as the first column. The mass ratio is according to the definition in the literature: $m / \rho D^2$ , where m does not include the added mass. However, structural mass, including trapped internal fluid mass is included if it was included in the mass/length in the input file.**

5. Fundamental natural frequency = 0.017623 Hz

**Section 5 lists the fundamental natural frequency of the structure (frequency of the first mode) based on either the internally calculated natural frequencies or the externally provided *.mds* file.**

6. Maximum flow velocity: 4.3000 ft/s
Minimum flow velocity: 1.0000 ft/s

**Section 6 lists the maximum and minimum currents provided in Block 3 of the input *.s7dat* file. For a uniform flow, the maximum and minimum current will be equal.**

7. The highest Strouhal frequency is: 0.11057(Hz) at node: 5
The lowest Strouhal frequency is: 0.02571(Hz) at node: 101

**Section 7 presents the maximum and minimum Strouhal frequencies found in the structure. All the possible excited modes should have its excitation frequency within this range.**

8. Minimum wavelength corresponding to the maximum flow velocity= 750.00(ft).

**The minimum wavelength is computed based on the average tension in the structure and the maximum VIV frequency.**

9. Modal damping ratio "zeta", modal mass,
and modal frequency for the mainly excited modes.

| Mode No. | zeta | n*zeta | modal mass (slug) | frequency (Hz) | zeta hydro | zeta material | standing exc zeta stick-slip | traveling exc zeta stick-slip |
|---|---|---|---|---|---|---|---|---|
| 3 | 0.04473 | 0.13420 | 107127.56 | 0.07888 | 4.173E-02 | 3.000E-03 | 0.000E+00 | 0.000E+00 |
| 4 | 0.03125 | 0.12500 | 107166.93 | 0.12786 | 2.825E-02 | 3.000E-03 | 0.000E+00 | 0.000E+00 |

**The modal damping ratio is the sum of the hydrodynamic damping (computed in the program) and the structural damping (from the input data file). n*zeta is the product of Mode no. and the modal damping ratio, see explanation of Section 2.4 of .s7out for further information.**

10. Information on mode overlap. There is mode overlap; the overlap part(s).

**Section 10 tells the user if the reduced velocity bandwidth selected has resulted in overlapping power-in regions. Power-in regions normally overlap, when more than one mode is above the cutoff.**

11. Modal Displacement Amplitude

| Mode No. | Combined Exc Modal Amp (ft) | Standing Exc Modal Amp (ft) | Traveling Exc Modal Amp (ft) | Standing Exc A_rms/D_ref | Traveling Exc A_rms/D_ref | Standing Exc c* | Traveling Exc c* | Uf | Standing Exc Beta | Traveling Exc Beta |
|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 2.92125 | 2.92471 | 2.91779 | 0.2421E+00 | 0.2404E+00 | 0.2045E+01 | 0.2111E+01 | 0.3005E+01 | 1.05642 | 1.05100 |
| 4 | 3.34489 | 3.34718 | 3.34260 | 0.2914E+00 | 0.2905E+00 | 0.1594E+01 | 0.1608E+01 | 0.4209E+01 | 1.02559 | 1.02260 |

Please note, the parameters of A*, c* and Uf are part of ongoing research. These parameters are intended to be interpreted in the context of being an ongoing R&D activity.
A* and c* have been calculated using the reference diameter which is specified by the end user.

**SHEAR7 is a mode superposition program. Item 11 gives the maximum magnitude of each resonant mode's contribution to the final sum, reported separately for standing and traveling wave excitations. It is the peak value and not an RMS value. In general this value will not exactly agree with the final response amplitude reported in Item 15.3 of the .s7out file. This is because the final response amplitude, even if at only one frequency, includes the contributions of resonant and non-resonant modes, as well as the combination of standing and traveling wave excitation response amplitudes.**

**$A^*$, $c^*$ and $U_f$ were added in version 4.9. $A^*$ is the spatial RMS value of the temporal RMS response amplitudes in the power-in region, normalized by the reference diameter. The diameter is the reference diameter that is specified by the user in the *.s7*dat file. $A^*$ includes the resonant and non-resonant modal contributions.**

**The parameter $c^*$ is a dimensionless damping parameter which is based on the equilibrium between power into the system from lift forces to the power out of the system due to damping. In general as damping is increased the response amplitude will fall. Also, it is generally true that even if the damping is constant, the response will increase with current speed. $c^*$ is a damping parameter that includes the effects of both damping coefficient as well as current speed on the response.**

**$U_f$ is the RMS current velocity in the power-in region.**

**For an in-depth description of $A^*$, $c^*$ and $U_f$ along with equations and plot examples, refer to Appendix H.**

**The beta value for a particular mode is defined as the ratio of the spatial maximum of the total response amplitude (includes contribution from both resonant and the non-resonant modes) to the resonant mode amplitude of that mode. When the beta number is equal to 1, the total response is primarily dominated by the resonant mode and the non-resonant terms do not have a significant contribution to the total response. When the number is significantly larger than 1, the non-resonant terms in the mode superposition solution become important. This ratio is crucial in determining the hydrodynamic lift and damping forces that SHEAR7 choses for a particular mode.**

**The reported beta values are the values calculated after the final iteration. When the beta control value is set to 0 in the input *.s7*dat, the beta values reported are calculated after the response is calculated.**

12. Modal excitation region.

Mode No. No. of Nodes Length Ratio

```
---------------------------------------
  3       13          0.129
  4       14          0.139

Portion of the structure which is subject to flow is
from 0.0400 L to 1.0000 L.
Portion of the structure which is out of water is
from 0.0000 L to 0.0400 L.
```

**Section 12 presents the number of nodes for each modal excitation region gives a direct measure of what fraction of the total length is used by that mode for power-in.**

**The exact location of those nodes is found by seeing where the lift is applied in Item 14. If equally spaced nodes were specified this information is in the *.s7log* file.**

13. Beta iteration for each mode.

```
Standing Wave Excitation

Iteration   Mode        Beta
------------------------------------
  0         3         1.056071
  0         4         1.025269
  1         3         1.056418
  1         4         1.025590

Traveling Wave Excitation

Iteration   Mode        Beta
------------------------------------
  0         3         1.056071
  0         4         1.025269
  1         3         1.051648
  1         4         1.022983
  2         3         1.051001
  2         4         1.022604

For multiple modes, the convergence criteria is applied
to each excited mode, using a threshold value of 5.0E-02.
```

**Section 13 presents the beta values calculated after each beta iteration, separated by standing and traveling wave excitation. The beta values for a particular mode and wave excitation type should be converging as the iterations progress. For multi mode cases, SHEAR7 stops the iterations when all the excited mode beta's become less than the convergence criteria, some modes may have converged more than other modes. If the beta iterations cause instability within the predicted response, the beta control value in the input *.s7*dat should be set to zero.**

14. Lift coefficient for each mode.

In the following, the lift coefficient Cl

is the amplitude and not the RMS value.
Iteration, change in Reynolds number,
and user input Cl reduction in suppression
zone are taken into account.

mode number: 3

| node number | Standing Exc Cl | Traveling Exc Cl | Fn/Fvo | VR |
|---|---|---|---|---|
| 18 | 0.6833 | 0.6841 | 0.8129 | 6.83 |
| 19 | 0.6840 | 0.6848 | 0.8441 | 6.58 |
| 20 | 0.6857 | 0.6864 | 0.8778 | 6.33 |
| 21 | 0.6881 | 0.6887 | 0.9143 | 6.08 |
| 22 | 0.6910 | 0.6915 | 0.9540 | 5.82 |
| 23 | 0.6941 | 0.6945 | 0.9973 | 5.57 |
| 24 | 0.6969 | 0.6972 | 1.0447 | 5.32 |
| 25 | 0.6990 | 0.6992 | 1.0968 | 5.07 |
| 26 | 0.7000 | 0.7000 | 1.1544 | 4.81 |
| 27 | 0.6973 | 0.6969 | 1.2184 | 4.56 |
| 28 | 0.6866 | 0.6859 | 1.2739 | 4.36 |
| 29 | 0.6667 | 0.6657 | 1.2954 | 4.29 |
| 30 | 0.6372 | 0.6361 | 1.3176 | 4.22 |

mode number: 4

| node number | Standing Exc Cl | Traveling Exc Cl | Fn/Fvo | VR |
|---|---|---|---|---|
| 5 | 0.6626 | 0.6619 | 1.1564 | 4.80 |
| 6 | 0.6935 | 0.6932 | 1.1566 | 4.80 |
| 7 | 0.6999 | 0.6999 | 1.1569 | 4.80 |
| 8 | 0.6966 | 0.6968 | 1.1572 | 4.80 |
| 9 | 0.6903 | 0.6906 | 1.1575 | 4.80 |
| 10 | 0.6826 | 0.6830 | 1.1578 | 4.80 |
| 11 | 0.6750 | 0.6754 | 1.1581 | 4.80 |
| 12 | 0.6687 | 0.6691 | 1.1584 | 4.80 |
| 13 | 0.6647 | 0.6652 | 1.1587 | 4.79 |
| 14 | 0.6636 | 0.6641 | 1.1590 | 4.79 |
| 15 | 0.6656 | 0.6659 | 1.1861 | 4.68 |
| 16 | 0.6702 | 0.6705 | 1.2269 | 4.53 |
| 17 | 0.6768 | 0.6771 | 1.2707 | 4.37 |
| 18 | 0.6845 | 0.6847 | 1.3176 | 4.22 |

**The reported lift coefficients are those values which result from the lift coefficient iteration as a function of A/D and the frequency ratio, separated by standing and traveling wave excitation.**

**They include all applied factors such as the lift coefficient reduction factor. Also tabulated in the fourth column is the normalized frequency ratio, as used in the .s7cl table. The fifth column gives the local reduced velocity at each node.**

**Whenever the user redirects Item 14 listing to the optional .s7*out1* file, the above listing is printed in that file and Item 14 of the .s7*out* file list the following instead:**

**"User requested that the contents of this item be redirected to an optionally generated file .s7*out1*."**

15. RMS response and damage rate at specified locations.
Modes used in mode superposition calculation are
from mode 1 to mode 16.
English units: displacement = ft;
acceleration=ft/s^2; stress=ksi.
RMS A/D is RMS displ /local hydro diameter

15.1 x/L RMS displ RMS A/D RMS acc RMS stress damage(1/years)

---

| | | | | | |
|---|---|---|---|---|---|
| 0.000 | 0.000 | 0.000 | 0.000E+00 | 9.720E-02 | 3.409E-06 |
| 0.100 | 2.126 | 0.304 | 0.130E+01 | 1.070E+01 | 1.596E+02 |
| 0.200 | 1.623 | 0.232 | 0.898E+00 | 7.137E+00 | 3.162E+01 |
| 0.300 | 1.319 | 0.188 | 0.827E+00 | 6.616E+00 | 2.742E+01 |
| 0.400 | 2.068 | 0.295 | 0.129E+01 | 1.032E+01 | 1.425E+02 |
| 0.500 | 0.967 | 0.138 | 0.286E+00 | 2.632E+00 | 1.049E+00 |
| 0.600 | 2.061 | 0.294 | 0.129E+01 | 1.011E+01 | 1.331E+02 |
| 0.700 | 1.272 | 0.182 | 0.798E+00 | 6.179E+00 | 2.109E+01 |
| 0.800 | 1.499 | 0.214 | 0.809E+00 | 6.279E+00 | 1.937E+01 |
| 0.900 | 2.152 | 0.307 | 0.131E+01 | 9.970E+00 | 1.230E+02 |
| 1.000 | 0.000 | 0.000 | 0.000E+00 | 6.953E-01 | 5.760E-03 |

**Section 15 is the summary of the VIV computation. Column 1 in the table specifies sample output points as specified by the user in the *.s7dat* file. Column 2 is the RMS response amplitude in real displacement units. Column 3 is Column 2 divided by the local diameter. If diameters change along the length one must beware as to the interpretation of this column. Columns 4, 5 and 6 are the RMS acceleration, stress and the fatigue damage rate. The fatigue damage rate is based on the RMS stress and the Rayleigh formula for damage rate, which assumes the stress comes from a narrow band random process.**

**The damage rate shown in the last column above has been multiplied by the probability of occurrence of the current profile.**

15.2 Maximum damage rate & its position for each excited mode

| Mode No. | Location (x/L) | damage rate | mode frequency (Hz) |
|---|---|---|---|
| 3 | 0.170 | 1.115E+00 | 0.07888 |

4 0.130 1.968E+02 0.12786

**The individual maximum modal damage rates given above have not been multiplied by the probability of occurrence of the current profile. In addition these individual rates will not be exactly the same as that shown in the *.s7plt* files or given in the response table above. The reason is that these rates are only for the individual resonant mode and do not include the non-resonant contributions of other modes at the same frequency. These modal maximum damage rates and their locations are given only to assist the engineer in determining potential trouble spots associated with particular modes. This may be useful in determining which regions are candidates for VIV suppression.**

15.3 The Overall Maximum RMS displacement (OMRD) is 2.302 ft
OMRD occurs at x/L= 0.130

15.4 The Overall Maximum RMS Stress (OMRS) is 1.1361E+01 ksi
OMRS occurs at x/L= 0.130

15.5 The Overall Maximum Fatigue Damage (OMFD) is 1.977E+02
OMFD occurs at x/L= 0.130

**The overall maximum values given in 15.3, 15.4 and 15.5 above, result from searching every nodal point in the *.s7plt* output file. These values include the contributions from all modes, resonant and non-resonant, and include the effect of the probability of occurrence of the current profile on the fatigue damage rate.**

16. Re,St,and drag amplification factor

| x/L | T (lbf) | V (ft/s) | Re | St | Cf |
|---|---|---|---|---|---|
| 0.000 | 224809.0 | 0.0000 | 0.0 | 0.180 | 1.000 |
| 0.100 | 249839.5 | 4.2935 | 2146774.2 | 0.180 | 1.754 |
| 0.200 | 274870.0 | 3.3550 | 1677500.0 | 0.180 | 1.633 |
| 0.300 | 299900.5 | 2.2883 | 1144141.6 | 0.180 | 1.553 |
| 0.400 | 324931.0 | 1.8891 | 944570.8 | 0.180 | 1.741 |
| 0.500 | 349961.5 | 1.4900 | 745000.0 | 0.180 | 1.452 |
| 0.600 | 374992.0 | 1.3885 | 694260.0 | 0.180 | 1.739 |
| 0.700 | 400022.5 | 1.2870 | 643520.1 | 0.180 | 1.540 |
| 0.800 | 425053.0 | 1.1856 | 592780.1 | 0.180 | 1.601 |
| 0.900 | 450083.5 | 1.0841 | 542040.2 | 0.180 | 1.760 |
| 1.000 | 475114.0 | 1.0000 | 500000.0 | 0.180 | 1.000 |

In the table, Cf is the drag amplification factor due to VIV response. The product of Cf and drag coefficient gives VIV amplified drag coefficient. T is effective tension.

**Section 16 is a useful check for a variety of items. One may also verify that the effective tension variation has been modelled correctly by checking the second column in item 16.**

**The local mean drag amplification factor, Cf, accounts for response caused amplification. This should be multiplied by the user chosen stationary cylinder CD value. The amplification factor depends on the rms A/D. This amplified CD value is a reasonable one to use in static configuration**

**calculations which require an estimate of the mean drag coefficient, including the effects of VIV. It should be noted that if the pure in-line flag is set then no cross-flow drag amplification is reported.**

17. Computational resolution.
The user-input number of spatial segments: 100
The program-suggested number of spatial segments: 20

The above value is defined as below.

It is assumed that the minimum wavelength equals twice of the structure length divided by the maximum mode number. It is also assumed that in each wavelength, 10 segments would be sufficient.

The user-input number of spatial segments should be greater than or at least equal to the above program-suggested value.

However, to adequately model the lift force distribution, the user-input number should not be too small. When the number of segments is small, the results can be sensitive to it.

**Users should avoid defining structural zones that are very short in length. This is especially relevant to third party software that provides automatic generation of SHEAR7 input files as output from their software.**

18. A Block 18 appears when running in stick-slip mode, which provides the critical curvatures for each node.

## 7.2 ROOT-NAME.S7PLT (ALWAYS CREATED)

The .s7*plt* file lists the calculated VIV response at each node of the structure. The *.s7plt* file is necessary when computing the fatigue damage accumulation for a given fatigue sea-state environment.

There are seven columns in the *.s7plt* file and they are described in Table 20. The units are also included in Table 20.

Table 20: PLT Columns

| Unit System | Response Location | RMS Displacement | RMS Velocity | RMS Acceleration | RMS Stress $S_{rms}$ | Damage Rate | Drag Coefficient Amplification Factor |
|---|---|---|---|---|---|---|---|
| SI | x/L | m | m/s | $m/s^2$ | $N/m^2$ | 1/year | - |
| English | x/L | ft | ft/s | $ft/s^2$ | ksi | 1/year | - |

When selecting the program to execute pure in-line VIV calculations the final column, drag coefficient amplification factor is not produced.

## 7.3 ROOT-NAME.S7MDS

The *.s7mds* is a file for the modal response of the structure which includes the natural frequency, mode shape, mode slope and mode curvature of the structure at each node location.

When calculation Option 2 or 3 is selected, then this file must be provided. This file is alternatively created by the program when the internal eigen solver is used in calculation Option 0 or 1. When the user chooses to provide the natural frequency, mode shape, slope and curvature, the same format must be followed.

The "*.s7mds*" file consists of three blocks. The structure of the *.s7mds* file can be obtained by running one of the example *.s7dat* files and opening the created *.s7mds* file. An *.s7mds* file has three blocks of data as described below. An excerpt from the **common.s7mds** file, provided to run example file **drill_riser_ext_modes.s7dat,** is presented in Table 21, including the complete data for Blocks 1 and 2 and the first few lines of Block 3.

Table 21: .s7mds Example –Even Nodal Spacing

| | | | | | |
|---|---|---|---|---|---|
| 5 | 201 | {Block 1} | | | |
| 1 | 0.17993 | {Block 2} | | | |
| 2 | 0.36101 | | | | |
| 3 | 0.54433 | | | | |
| 4 | 0.73101 | | | | |
| 5 | 0.92202 | | | | |
| 1 | 1 | 0.00E+00 | 1.93E-03 | 0.00E+00 | {Block 3} |
| 1 | 2 | 1.96E-02 | 1.93E-03 | -7.71E-07 | |
| 1 | 3 | 3.92E-02 | 1.92E-03 | -8.28E-07 | |
| 1 | 4 | 5.86E-02 | 1.91E-03 | -8.83E-07 | |
| 1 | 5 | 7.80E-02 | 1.90E-03 | -9.38E-07 | |

The structure of the .s7mds file is as follows:

- Block 1 – This block has one line with two numbers, the number of modes (in this example, 5) and the number of nodes (in this example, 201) used to specify the mode shape. The number of nodes is always the number of segments plus 1.
- Block 2 – This block has a number of lines equal to the number of modes specified in the first block. Each line has two numbers, the first is the mode number and the second is the natural frequency (in radians/second). The mode numbers and natural frequencies are presented in ascending order.
- Block 3 – This block normally has five columns of numbers. The description and units of each of these columns are presented in Table 22. A sixth column of x/L values is added for mode 1 only, when uneven nodal spacing is desired. The order of the columns are as follows:

- The first column is the mode number.
- The second column is the node number.
- The third column is the mode shape. The mode shape is a normalized one, with the maximum amplitude being unity. When using the Varying Structural Damping module [5.6.22 and Appendix I ] (implemented in v4.11), it is necessary to include the mode slope column.
- The fourth column is the mode slope. The computed mode slope is based on the normalized mode shape and the axial length in the units selected. The mode slope is that which would result from a mode shape with unit amplitude. The mode slope values are always required, even if all are set to 0.0, but they are used only in conjunction with structural (nmodels) 1 and 10 and only when gravity is to be included in the predicted RMS acceleration.
- The fifth column is the mode curvature. The computed mode curvature is based on the normalized mode shape and the axial length in the units selected. The mode curvature is that which would result from a mode shape with unit amplitude.
- An optional sixth column is for the specification of uneven nodal spacing. Non-uniform spacing can only be used for program calculation Option 2 or 3, which requires the user to prepare in advance a common.s7mds or .mds file. In order to invoke the non-uniform spacing, the user provides the x/L values at each node as an additional sixth column of numbers in the mds file for the first mode only, as seen in Table 23.
- Block 3 begins with the lowest mode first and lowest node first and then lists the values for every node of that mode. Then the next mode is listed.

- There is no blank line in between blocks.

Table 22: S7MDS Block 3 Column Units

| Unit System | Column 1 | Column 2 | Column 3 | Column 4 | Column 5 | Column 6 (optional) |
|---|---|---|---|---|---|---|
| | Mode Number | Node Number | Mode Shape | Mode Slope | Mode Curvature | Uneven X/L Values |
| SI | - | - | m | m/m | rad/m | - |
| English | - | - | ft | ft/ft | rad/ft | - |

Table 23: .s7mds Example – Uneven Nodal Spacing

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | 201 | {Block 1} | | | | |
| 1 | 0.17993 | {Block 2} | | | | |
| 2 | 0.36101 | | | | | |
| 3 | 0.54433 | | | | | |
| 4 | 0.73101 | | | | | |
| 5 | 0.92202 | | | | | |
| 1 | 1 | 0.00E+00 | 1.95E-03 | 0.00E+00 | 0.00E+00 | {Block 3} |
| 1 | 2 | 1.98E-02 | 1.94E-03 | -7.78E-07 | 5.00E-03 | |
| 1 | 3 | 3.95E-02 | 1.93E-03 | -8.37E-07 | 1.00E-02 | |
| . | | | | | | |
| . | | | | | | |
| . | | | | | | |
| 1 | 199 | 2.20E-02 | -1.09E-03 | 2.11E-07 | 9.90E-01 | |
| 1 | 200 | 1.10E-02 | -1.09E-03 | 2.20E-07 | 9.95E-01 | |
| 1 | 201 | 0.00E+00 | -1.08E-03 | 0.00E+00 | 1.00E+00 | |
| 2 | 1 | 0.00E+00 | 3.75E-03 | 0.00E+00 | | |
| 2 | 2 | 3.80E-02 | 3.73E-03 | -1.81E-06 | | |
| 2 | 3 | 7.59E-02 | 3.71E-03 | -2.29E-06 | | |
| . | | | | | | |
| . | | | | | | |
| . | | | | | | |
| 2 | 199 | -4.27E-02 | 2.11E-03 | -2.82E-07 | | |
| 2 | 200 | -2.12E-02 | 2.11E-03 | -3.64E-07 | | |
| 2 | 201 | 0.00E+00 | 2.11E-03 | 0.00E+00 | | |
| . | | | | | | |
| . | | | | | | |

### 7.3.1 Common.s7mds Files For Option 2 Or Any .mds File For Option 3:

**NOTE:** The number of modes required by SHEAR7 was modified in version v4.10 from 1.5 times the maximum vortex shedding frequency to 4 times the maximum potentially excited mode number.

The .s7mds file prepared by FEA programs should follow the same convention as it is presented in Table 21 for even nodal spacing and Table 23 for uneven nodal spacing.

The modal range defined in the *.mds* file should be large enough so that it covers all possible excited modes in all current states to be used plus at least a multiple of 4.0 times higher mode numbers. If not enough modes are supplied in the *.mds* file the program will stop and the following error message will be presented in the .s7out file:

- *"The modes supplied are not sufficient.*
  *Natural frequencies up to at least 4.0 times the maximum potentially excited mode number.*
  *The program stops.*
  *Please provide additional modes in the MDS file."*

One way to determine the number of modes for the **maximum current case** is to first run the program with calculation Option 1 and with a trial current profile which has the maximum current intended in all profiles to be used. SHEAR7 will use its internal model of, for example a beam with linearly varying tension to compute the required natural frequencies and mode shape information. By checking the root-name.s7 file the user can determine the natural frequency (in rad/sec) of the highest mode used in the run. The user then prepares a common.s7mds file, typically using a finite element program. The FEA modes must have natural frequencies which are at least as large as the largest one found in the root-name.s7mds file after running under Option 1.

It is noted, that when generating common.s7mds or .mds files from FEA, it is advisable to use slope and curvature values computed by the FEA programs and NOT TO USE simple deflection or/and slope numerical differentiation schemes from spreadsheets. The latter can lead to significant errors or even cause the program to stop, in particular when high mode numbers are excited. It is noted that, for example, both ABAQUS and ANSYS programs compute all the values required for the generation of the common.s7mds or .mds file.

When using certain 3rd party FEA programs to generate the common.s7mds or .s7mds, it is suggested that a current of a small magnitude be applied for identification of the environmental direction (e.g., cross-flow or in-line flow). It is recommended that a sensitivity study be carried out to ensure the current does not substantially change the mean shape of the structure. If the mean shape changes substantially you should create different structural models representing each mean shapes.

The externally prepared .s7mds file must be for "wet" natural frequencies and modal shapes.

If performing many runs using calculation Option 1 (where SHEAR7 calculates natural frequencies and modal shapes) it may be advantageous to run the maximum current case first, rename the resulting root-name.s7mds file to common.s7mds, and then switch the calculation option to Option 2 for all remaining computations. This saves the computation time of repeatedly computing the

modal frequency and shape information. For a riser with high mode number this can be a significant fraction of the total computation time.

## 7.4 ROOT-NAME.S7ANM

To enable creation of the *.s7anm* file a '1' should be entered next to "flag for MATLAB animation data output 1=yes;0=no)". *.s7anm* files can be used to create a time domain animation of the response of the system.
The user should normally not need to request that the program create this file.

## 7.5 ROOT-NAME.S7LOG

The *.s7log* file generated by SHEAR7 assists in debugging program execution problems.

The data is written to the *.s7log* file as soon as it is computed by the program. In the case the program execution stops the user can determine where the problem occurs by how far through the execution the program has proceeded as reported in the *.s7log* file.

The first blocks of the *.s7log* file contain an echo of the input data. The input echoes are written to the *.s7log* file almost immediately after the input has been read by SHEAR7. When the program stops before writing anything in the *.s7out* file, the error may be identified by seeing at what point the input data echo stops in the *.s7log* file. The problem is usually in the specification of the input data at that point.

After the input echo, SHEAR7 will assign the nodes from the .mds file to the zones defined in Block 2. The following describes the procedure used by SHEAR7 in assigning nodes to zones:

- First SHEAR7 identifies in which zone each segment lies. The position of the mid-point is taken as defining the zone containing the segment. If the segment lies wholly in the zone containing its midpoint, then it is given the properties of that zone.
- However, for compatibility with prior versions of SHEAR7 if one end of the segment lies in an adjacent zone, the segment is given a combination of the properties of the two zones, in proportion to the length of the segment lying in each of the two zones.
- If both ends of a segment are determined to be in adjacent zones to the zone containing the midpoint of the segment, or a zone is found which contains no segments then a warning that the zone size is too small is issued and the program is halted.
- Having identified the zones containing the start, midpoint and end of the segment, properties associated with the containing zones are allocated to the segment.

An example of the segment allocation into the zones is presented in Table 24

Table 24: .s7log Example – Segment Allocations Into Zones

| |
|---|
| End of input data echo |
| Segment 1 in zone 1 - both ends in zone |
| Segment 2 in zone 1 - both ends in zone |
| Segment 3 in zone 2 - one end out of zone |
| Segment 4 in zone 2 - both ends in zone |
| Segment 5 in zone 3 - one end out of zone |
| . |
| . |
| Segment 198 in zone 9 - both ends in zone |
| Segment 199 in zone 9 - one end out of zone |
| Segment 200 in zone 10 - both ends in zone |

The *.s7log* file also gives tabular summaries of preliminary and final computations. An example excerpt from execution of an example file is shown in Table 25. The table showing preliminary calculations pertains to the power-in regions, computed before the power cut-off is applied.

A similar table pertaining to the final calculation stage corresponds to the final set of results is presented in Table 26. Please note that in the example shown, only Modes 2 and 4 are above the power cut-off, and accordingly the table reports zeros in the Mode 3 column for all nodes, including those, where Mode 3 was excited in the preliminary calculation.

Both tables have been designed for scrolling and/or for easy export to a spreadsheet or other programs for plotting.

## Table 25: .s7log Preliminary Calculation Example

| Preliminary Calculation, Mode Power-in (& overlap) Summary for each Node: | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Node# | Power-in node locations marked with Mode #, if non-zero | | | | | | | |
| 1 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 0 |
| 2 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 0 |
| 3 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 0 |
| 4 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 0 |
| 5 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 7 |
| 6 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 7 |
| 7 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 7 |
| 8 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 7 |
| 9 | 0 | 0 | 0 | 4 | 5 | 0 | 0 | 7 |
| . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . |
| . | . | . | . | . | . | . | . | . |
| 98 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 99 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 100 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## Table 26: .s7log Final Calculation Example

| Final  Calculation, Mode Power-in (& overlap) Summary for each Node: | | | |
|---|---|---|---|
| Node# | Power-in node locations marked with Mode #, if non-zero | | |
| 1 | 0 | 0 | 4 |
| 2 | 0 | 0 | 4 |
| 3 | 0 | 0 | 4 |
| 4 | 0 | 0 | 4 |
| 5 | 0 | 0 | 4 |
| 6 | 0 | 0 | 4 |
| 7 | 0 | 0 | 4 |
| 8 | 0 | 0 | 4 |
| 9 | 0 | 0 | 4 |
| . | . | . | . |
| . | . | . | . |
| . | . | . | . |
| 98 | 2 | 0 | 0 |
| 99 | 2 | 0 | 0 |
| 100 | 2 | 0 | 0 |

## 7.6 ROOT-NAME.S7DMG

This file includes the unfactored (not multiplied by the time shared probability) Rayleigh fatigue damage rate per year for each excited mode and its time sharing probabilities. This file can be used for independently summing the fatigue damage using alternative techniques to the in-built SHEAR7 methodology.

This file is divided into two blocks as follows:

- Block 1 – This block includes three columns. The first column includes each of the excited modes for which Rayleigh fatigue damage per year is listed in Block 2. Column 2 lists the frequency in Hertz of each of the excited modes. Column 3 lists the time sharing probabilities for each of the listed modes.
- Block 2 – This block includes the listing of unfactored (not multiplied by the time shared probability) Rayleigh fatigue damage per year computed for each of the above modes at each riser node. x/L node locations are listed in Column 1 of Block 2, the Rayleigh damage results are listed in the remaining columns, with the mode number corresponding to that column listed in the first row. Whenever there are interruptions in the mode sequence numbers that make it above the power cut-off, zero time sharing probabilities are written to Column 3 of Block 1 in the mode number corresponding.
- An example of the *.s7*dmg file is presented in Table 27. In this example Modes 2 and 4 are above the power cut-off and this is why the time sharing probability and fatigue damage rate is 0.0 for Mode 3, as Mode 3 did not make the power cut-off. Also, in this example the time sharing probabilities listed for Modes 2 and 4 are each equal to 1.0, because these modes belong to different independent time sharing zones.

Table 27: *.s7*dmg Example 1

| Mode | Frequency (Hz) | Time Sharing Ratio | |
|---|---|---|---|
| 2 | 0.0426 | 0.100E+01 | |
| 3 | 0.0788 | 0.000E+00 | |
| 4 | 0.1277 | 0.100E+01 | |
| x/L | 2 | 3 | 4 |
| 0.0000 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 0.0100 | 5.1991877602E-13 | 0.0000000000E+00 | 1.2182084145E-12 |
| 0.0200 | 3.7888735420E-12 | 0.0000000000E+00 | 8.7792327888E-12 |
| 0.0300 | 1.0996537084E-11 | 0.0000000000E+00 | 2.4970489831E-11 |
| 0.0400 | 2.1029258596E-11 | 0.0000000000E+00 | 4.6332236891E-11 |
| 0.0500 | 3.0894700576E-11 | 0.0000000000E+00 | 6.5250469854E-11 |
| . | . | . | . |
| . | . | . | . |
| 0.9900 | 3.7097079272E-11 | 0.0000000000E+00 | 7.3955126458E-11 |
| 1.0000 | 3.7292303619E-11 | 0.0000000000E+00 | 6.8689583834E-11 |

- It should be noted that for the fatigue damage calculations that are used by SHEAR7 and reported in the *.s7out* and the *.s7plt* files the fatigue damage is multiplied by the time sharing probabilities listed in Line 2 of Block 1 of the *.s7dmg* file (same as those listed in Table 2.2.1 of the .s7*out* file). The results listed in Block 2 of *.s7dmg* are unfactored, so that the user can do independent post-processing.
- If zero-crossing fatigue calculation is used, the *.s7*dmg file specifies this as the first line. The second line notes that the using the zero-crossing method the time sharing ratio will be 1.0. The remainder of the file has three columns: respectively node x/L value, zero-crossing damage rate, and zero-crossing frequency (radians/second). It should be noted that the zero-crossing fatigue damage presented in this file is exactly the same as the damage reported in the .s7plt.
- An example of the *.s7*dmg file when the zero-crossing fatigue calculation is used is presented in Table 28.

Table 28: *.s7*dmg Example 2

Zero crossing method is used.

Time sharing ratio is 1.0.

| x/L | Damage Rate | Zero Crossing Frequency (rad/s) |
|---|---|---|
| 0 | 0.00E+00 | 0.00E+00 |
| 0.01 | 4.90E-06 | 2.34E+01 |
| 0.02 | 8.38E-05 | 2.34E+01 |
| 0.03 | 4.23E-04 | 2.34E+01 |
| 0.04 | 1.28E-03 | 2.34E+01 |
| 0.05 | 2.87E-03 | 2.33E+01 |
| 0.06 | 5.30E-03 | 2.33E+01 |
| 0.07 | 8.47E-03 | 2.33E+01 |

## 7.7 ROOT-NAME.S7FAT

This file is intended to be used externally to calculate fatigue damage by user-defined techniques. It contains the modal participation and frequency response characteristics of each mode and the probability of occurrence. The 'Wave Excitation' column indicates, via a 0 or 1, whether the reported row was derived from the standing wave excitation calculations (0), or the traveling wave excitation calculations (1). If a traveling wave excitation ratio of 0.0 is used, then traveling wave excitation calculations are not run and its results are not recorded in the file.
The nine columns in the .s7fat file and the respective units are presented in Table 29.

Table 29: .s7fat Columns

| Units | Mode | Assoc | Freq | Mode Amp | Mode Phase | Mode Force | Mode Prob | Excitation Zone | Wave Excitation |
|---|---|---|---|---|---|---|---|---|---|
| SI | - | - | (rad/s) | (m) | (radians) | (N) | - | - | - |
| English | - | - | (rad/s) | (ft) | (radians) | (lbf) | - | - | - |

The usefulness of the this file has diminished with the availability of the .s7str file.

## 7.8 ROOT-NAME.S7OUT1

The reason for creating this file is to decrease the size of the .s7*out* file, in particular for high aspect ratio models, where many modes can be present. With the above flag set to default zero no .s7*out1* file is generated. With the flag set to '1' or to '2' the printout of the lift coefficient for each mode is redirected to the .s7*out1* file. The .s7*out1* file include the listings of the lift coefficient, the non-dimensional frequency and the reduced velocity in the power-in zones.

Below is an example of the .s7*out1* file output. The format is identical to that used in Item 14 of the .s7*out* file, whenever the .s7*out1* or the .s7*out1* and .s7*out2* files are not generated.

Table 30: .s7out1 Example

Lift coefficient for each mode.

In the following, the lift coefficient Cl is the amplitude and not the RMS value. Iteration, change in Reynolds number, and user input Cl reduction in suppression zone are taken into account.

mode number: 4

| node number | Standing Exc Cl | Traveling Exc Cl | Fn/Fvo | VR |
|---|---|---|---|---|
| 5 | 0.692 | 0.6880 | 0.8661 | 4.81 |
| 6 | 0.6998 | 0.6883 | 0.8663 | 4.81 |
| 7 | 0.6954 | 0.6888 | 0.8665 | 4.81 |
| 8 | 0.6867 | 0.6895 | 0.8667 | 4.81 |
| 9 | 0.6758 | 0.6904 | 0.867 | 4.81 |
| 10 | 0.6646 | 0.6913 | 0.8672 | 4.8 |
| 11 | 0.6549 | 0.6924 | 0.8674 | 4.8 |
| 12 | 0.6481 | 0.6936 | 0.8676 | 4.8 |
| 13 | 0.645 | 0.6948 | 0.8678 | 4.8 |
| 14 | 0.6461 | 0.6960 | 0.868 | 4.8 |
| 15 | 0.6512 | 0.6971 | 0.8883 | 4.69 |
| 16 | 0.6596 | 0.6981 | 0.9189 | 4.53 |
| 17 | 0.6702 | 0.6989 | 0.9517 | 4.38 |
| 18 | 0.6815 | 0.6996 | 0.9869 | 4.22 |
| 19 | 0.6914 | 0.6999 | 1.0248 | 4.07 |
| 20 | 0.6982 | 0.6999 | 1.0657 | 3.91 |
| 21 | 0.6992 | 0.6986 | 1.11 | 3.75 |
| 22 | 0.6772 | 0.6957 | 1.1582 | 3.6 |
| 23 | 0.6205 | 0.6909 | 1.2108 | 3.44 |
| 24 | 0.525 | 0.6251 | 1.2683 | 3.29 |
| 25 | 0.3884 | 0.4011 | 1.3316 | 3.13 |

## 7.9 ROOT-NAME.S7OUT2

With the flag Option '2' both the .s7*out1* & the .s7*out2* are generated and the contents of Item 13 of the .s7*out* file is redirected to the .s7*out1* file, as described in Section 7.8.

The .s7*out2* file includes only numbers and it contains entries pertinent to all the resonant modes for all nodes of the structure. The format of the .s7*out2* file resembles those of the *.mds* and the *.s7dmg* files.

There are seven columns in the .s7out2 file and they are presented in Table 31. The units for each are also shown in Table 31.

Table 31: .s7out2 Columns

| Units | Mode Number | Node Number | Standing Excitation Lift Coefficient Value[1,2] | Traveling Excitation Lift Coefficient Value[1,2] | Sectional Damping[2,3] | Non Dimensional Frequency[3] | Reduced Velocity[3] |
|---|---|---|---|---|---|---|---|
| SI | - | - | - | - | N·s/m² | - | - |
| English | - | - | - | - | lbf·s/ft² | - | - |

Notes:
1. Whenever the node is outside the power-in zone, the lift coefficient is zero and sectional damping is used if the node is submerged. In order to differentiate between an accidental zero value of the lift coefficient in a power-in zone, lift coefficient code = 99 is listed instead of the value zero used by the program outside the power-in regions.
2. Whenever the node is in the power-in region the lift coefficient is used and the sectional damping is zero.
3. Whenever a node is out of water, zeros are listed in columns 4 to 6 of the .s7out2 file.

The lift coefficient values, the non dimensional frequency and the reduced velocity are the same as those listed in the .s7*out1* file for all the power-in nodes of the resonant modes.

Table 32 presents an example of the .s7out2 file. In the example it should be observed that:

- Nodes 1 through 4 are out of water;
- Nodes 5 through 25 are in a power-in region
- Nodes 26 through 34 are submerged, but they are outside the power-in region; code 99 in Column 3 is interpreted as a zero value of the lift coefficient.
- Traveling wave excitation calculations were not run, and therefore all values are code 99 for the lift coefficient

It is noted that requesting the printing of the .s7*out2* file is a convenient way of obtaining a listing of the non-dimensional frequencies and those of the reduced velocities outside the power-in regions. Cross-checking those values would usually be of an optional interest.

Table 32: .s7out2 Example

| Mode Number | Node Number | Standing Excitation Lift Coefficient Value | Traveling Excitation Lift Coefficient Value | Sectional Damping | Non Dimensional Frequency | Reduced Velocity |
|---|---|---|---|---|---|---|
| 4 | 1 | 99 | 99 | 0 | 0 | 0 |
| 4 | 2 | 99 | 99 | 0 | 0 | 0 |
| 4 | 3 | 99 | 99 | 0 | 0 | 0 |
| 4 | 4 | 99 | 99 | 0 | 0 | 0 |
| 4 | 5 | 0.692 | 99 | 0 | 0.8661 | 4.81 |
| 4 | 6 | 0.6998 | 99 | 0 | 0.8663 | 4.81 |
| 4 | 7 | 0.6954 | 99 | 0 | 0.8665 | 4.81 |
| 4 | 8 | 0.6867 | 99 | 0 | 0.8667 | 4.81 |
| 4 | 9 | 0.6758 | 99 | 0 | 0.867 | 4.81 |
| 4 | 10 | 0.6646 | 99 | 0 | 0.8672 | 4.8 |
| 4 | 11 | 0.6549 | 99 | 0 | 0.8674 | 4.8 |
| 4 | 12 | 0.6481 | 99 | 0 | 0.8676 | 4.8 |
| 4 | 13 | 0.645 | 99 | 0 | 0.8678 | 4.8 |
| . | . | . | 99 | . | . | . |
| . | . | . | 99 | . | . | . |
| 4 | 26 | 99 | 99 | 15.665 | 1.4015 | 2.97 |
| 4 | 27 | 99 | 99 | 90.8041 | 1.4792 | 2.82 |
| 4 | 28 | 99 | 99 | 238.6794 | 1.5466 | 2.69 |
| 4 | 29 | 99 | 99 | 449.8295 | 1.5726 | 2.65 |
| 4 | 30 | 99 | 99 | 710.4557 | 1.5996 | 2.6 |
| 4 | 31 | 99 | 99 | 1003.781 | 1.6275 | 2.56 |
| 4 | 32 | 99 | 99 | 1310.984 | 1.6564 | 2.52 |
| 4 | 33 | 99 | 99 | 1612.401 | 1.6863 | 2.47 |
| 4 | 34 | 99 | 99 | 1888.694 | 1.7174 | 2.43 |

## 7.10 ROOT-NAME.S7STR AND .S7CURV

The format of the optionally produced .s7str or .s7curv file is exactly the same, except one has temporal rms stress, while the other has temporal peak curvature. The following described the .s7str format.

The .s7str file includes the listing of rms stress ($Sr_{RMS}$) computed for each resonant mode at each structural node. User's can use the results within the .s7*str* file to calculate fatigue.

This file is divided in 2 blocks as follows:

- Block 1 – This block lists the mode numbers for which $Sr_{RMS}$ is listed in Block 2 as well as the mode corresponding frequency in Hertz and the time sharing probability.
- Block 2 – This block includes the listing of rms stress computed for each resonant mode ($Sr_{RMS}$) at each riser node. x/L node locations are listed in column 1 of Block 2, $Sr_{RMS}$ are listed in the remaining columns under the corresponding mode number. Whenever there are interruptions in the mode sequence numbers that make it above the power cut-off, zero time sharing probabilities are written to Column 3 of Block 1 in the rows corresponding.
- An example of the .s7str file is presented in Table 33. In this example Modes 2 and 4 are above the power cut-off and this is why the time sharing probability and rms stress is 0.0 for Mode 3, as Mode 3 did not make the power cut-off. Also, in this example the time sharing probabilities listed for Modes 2 and 4 are each equal to 1.0, because these modes belong to different independent time sharing zones.

Table 33: .s7str Example 1

| Mode | Frequency (Hz) | Time Sharing Ratio | |
|---|---|---|---|
| 2 | 0.0426 | 0.100E+01 | |
| 3 | 0.0788 | 0.000E+00 | |
| 4 | 0.1277 | 0.100E+01 | |
| x/L | 2 | 3 | 4 |
| 0.0000 | 0.0000000000E+00 | 0.0000000000E+00 | 0.0000000000E+00 |
| 0.0100 | 2.7102857828E-01 | 0.0000000000E+00 | 5.4839358330E+00 |
| 0.0200 | 5.3813177347E-01 | 0.0000000000E+00 | 1.0895046234E+01 |
| 0.0300 | 8.0271208286E-01 | 0.0000000000E+00 | 1.6168802261E+01 |
| 0.0400 | 1.0636179447E+00 | 0.0000000000E+00 | 2.1240566254E+01 |
| 0.0500 | 1.3198379278E+00 | 0.0000000000E+00 | 2.6047800064E+01 |
| . | . | . | . |
| . | . | . | . |
| 0.9900 | 2.0496296883E+00 | 0.0000000000E+00 | 3.8310447693E+01 |
| 1.0000 | 2.2766475677E+00 | 0.0000000000E+00 | 4.1512439728E+01 |

- If zero-crossing fatigue calculation is used the format of the .s7str changes. The first line of the .s7str file specifies that the zero-crossing method has been used. The second line indicates that the using the zero-crossing method the time sharing ratio will be 1.0. The remainder of the file has three columns: respectively node x/L value, rms stress, and zero-crossing frequency (radians/second).
- An example of the .s7str file when the zero-crossing fatigue calculation is used is presented in Table 34.

Table 34: .s7str Example 2

| Zero crossing method is used.<br>Time sharing ratio is 1.0. | | |
|---|---|---|
| x/L | RMS Stress | Zero Crossing Frequency (rad/s) |
| 0 | 0.00E+00 | 0.00E+00 |
| 0.01 | 8.52E+05 | 2.34E+01 |
| 0.02 | 1.69E+06 | 2.34E+01 |
| 0.03 | 2.49E+06 | 2.34E+01 |
| 0.04 | 3.25E+06 | 2.34E+01 |
| 0.05 | 3.96E+06 | 2.33E+01 |
| 0.06 | 4.59E+06 | 2.33E+01 |
| 0.07 | 5.14E+06 | 2.33E+01 |

## 7.11 ROOT-NAME.S7STH AND .S7DTH AND .S7CTH

The .s7sth file produces an optional stress time history. The .s7dth file produces an optional displacement time history. The .s7cth produces an optional curvature time history. All .s7sth, .s7dth, and .s7cth have identical formats; the rest of this sub-section only refers to .s7sth however it also applies to .s7dth and .s7cth, replacing 'stress' with 'displacement' or 'curvature'.

The .s7sth file includes a time history of predicted stress computed for each resonant frequency at selected structural nodes. This file is a comma delimited file.

This file output is shown in Table 35. In this example:

- Block 1 – This block lists the input parameter for the stress time history module.
- Block 2 – This block presents the stress at selected nodes as a function of time. The columns labeled "Zone 1", "Zone 2" and "Zone 3" represent the, up to, three time sharing power-in zones and the listed number is the mode number that is excited in that zone at that time instant.
- An example of the .s7sth file is presented in Table 35. In this example Three nodes have been selected for output: 1, 48 and 251. There are two time sharing power-in zones. For the first two time steps mode number 16 will be excited in time share zone 1 and mode number 2 will be excited in time share zone 2. The time sharing zones are independent of one another therefore both of these modes are acting at once.

Table 35: .s7sth Example 1

| | | | | | |
|---|---|---|---|---|---|
| 3.600e+3 | Total Time (seconds) | | | | |
| 3.956E-01 | Sample Time (seconds) | | | | |
| 123 | Random number Seed | | Nodes –> | | |
| Time | Zone 1 | Zone 2 | 1 | 48 | 251 |
| 0.0000 | 16 | 2 | 0.000E+00 | 0.000E+00 | 0.000E+00 |
| 3.956E-01 | 16 | 2 | 5.334E+00 | 6.344E+00 | 7.564E+00 |
| . | . | . | . | | |

# 8 .S7DAT FILE CONVERSION PROGRAM

A program for automatic conversion of SHEAR7 version 4.12 to 5.0 *.s7dat* files is provided. It is called **convert_v412_to_v50.exe**.

This program will convert all of the .s7dat files in a directory from version 4.12 .s7*dat* files to 5.0 .*s7*dat files. **The each file is *overwritten with the changes*.** Therefore, if you want to retain the original version 4.12 *.s7dat* files then put a copy in a separate directory.

To use the program, the required *.s7dat* files should be dragged over the top of the **convert_v412_to_v50.exe** program then release.

The conversion program sets the traveling wave excitation ratio as 0.5. Changing this to 0.0 will result in almost identical results as v4.12c. The user needs to check the converted file to ensure the values used are appropriate for their modeling situation.

# 9 AVAILABLE EXAMPLES

The available SHEAR7 examples are presented in Tables 36 to 42. The SHEAR7 example *.s7*dat files are located in the "<InstallationDir>\Example Files" directory of SHEAR7 upon installation. The implementation of one of the example files from design data is presented in Appendix D.

**It is noted that the axial flow damping capability available since SHEAR7 version 4.9 remains as an experimental feature and is yet to be fully verified. Further testing has been planned for calibration against other model tests and field data. Although Axial Damping Coefficients are available from regulations associated with offshore analysis, these have not been verified for VIV predictions in SHEAR7. It is recommended that users set this parameter to 0.0 for their analyses.**

Table 36: Basic Modeling Examples

| File Name | Description | Units (flag) | Calculation Option | Structural Model | | | | SN-Curve | SCF | Suppression | Beta Iteration | Traveling Wave Excitation Ratio | Non-Orthogonal Damping |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Code | Type | B.C | Tension | | | | | | |
| basic_cable | cable response | English (1) | 1 | 0 | string | pinned-pinned | varying | ASME | 1.0 | no | 10 | 0.5 | 1 |
| basic_beam_1 | response of tensioned beam | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X | 1.0 | no | 10 | 0.5 | 1 |
| basic_beam_2 | response of tensioned beam | SI (0) | 1 | 1 | beam | pinned-pinned | varying | API-X | 1.0 | no | 10 | 0.5 | 1 |
| basic_beam_3 | response of tensioned beam with boundary rot spring | English (1) | 1 | 6 | beam | pinned w/spring | varying | API-X' | 1.0 | no | 10 | 0.5 | 1 |
| basic_beam_multi_sn [1] | multiple S-N data specified example | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X and ASME | 1.0 | no | 10 | 0.5 | 1 |

Notes:
1. This example file cannot be run when using an Academic License.

Table 37: Riser System Examples

| File Name | Description | Units (flag) | Calculation Option | Structural Model | | | | SN-Curve | SCF | Suppression | Beta Iteration | Traveling Wave Excitation Ratio | Non-Orthogonal Damping |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Code | Type | B.C | Tension | | | | | | |
| drill_riser_staggered_buoy | drilling riser with multiple structural zones including buoyancy | SI (0) | 1 | 1 | beam | pinned-pinned | varying | API-X | 1.0 | no | 10 | 0.5 | 1 |
| drill_riser_ext_modes | drilling riser response (importing modes) common.mds file is provided | English (1) | 2 | 999 | beam | pinned-pinned | varying | API-X' | 1.0 | no | 10 | 0.5 | 1 |
| scr_import_tension | steel catenary (export) riser response (importing tension) common.cat file is provided. An animation file is created. | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X' | 1.0 | no | 10 | 0.5 | 1 |
| scr_inclined_cat | inclined catenary response | English (1) | 1 | 33 | Catenary | pinned-pinned | varying | API-X | 1.0 | no | 10 | 0.5 | |

Table 38: Varying Structural Damping “Stick-Slip” Examples

| File Name | Description | S (flag) | Calculation Option | Structural Model | | | | SN-Curve | | Suppression | Beta Iteration | Traveling Wave Excitation Ratio | Hysteresis Definition File |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Code | Type | B.C | Tension | | | | | | |
| OMAE2016-54816-exmpl-v411-Umb1.s7dat[1] | An unbonded flexible umbilical case exhibiting stick-slip behavior | SI (0) | 3, "slope_added_1000.s7mds" | 999 | Import from s7mds file | Import from s7mds file | defined in common.s7cat | N/A | N/A | no | 4 | 0.0 | Umb01-N.s7inhyst |

Notes:
1. The parameters used for this example are consistent with the default parameters from v4.11b of SHEAR7.

Table 39: Time Sharing Function Examples

| File Name | Description | Units (flag) | Calculation Option | Structural Model | | | | SN-Curve | SCF | Suppression | Beta Iteration | Traveling Wave Excitation Ratio | Non-Orthogonal Damping |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Code | Type | B.C | Tension | | | | | | |
| time_share_1 | One (1) independent time sharing zones on the riser. Miami2 case, full time sharing (Ampl. limit = 0.0) | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X' | 1.0 | no | 10 | 0.5 | 1 |
| time_share_2 | Two (2) independent time sharing zones on the riser. Miami2 case, full time sharing (Ampl. limit = 0.4) see Table 2.2.1 in .s7out file | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X' | 1.0 | no | 10 | 0.5 | 1 |
| time_share_3 | Three (3) independent time sharing zones on the riser. High mode Miami2 case, full time sharing (Ampl. limit = 1.0) | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X' | 1.0 | no | 10 | 0.5 | 1 |

Table 40: Strake Modeling Examples

| File Name | Description | Units (flag) | Calculation Option | Structural Model | | | | SN-Curve | SCF | Suppression | Beta Iteration | Traveling Wave Excitation Ratio | Non-Orthogonal Damping |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Code | Type | B.C | Tension | | | | | | |
| strake_1 | TTR with upper 85% strake coverage in GOM. Recommended strake modeling table (5). | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X' | 1.0 | yes | 10 | 0.5 | 1 |
| strake_2 | TTR with upper 40% strake coverage in GOM. Shows example with high performance strakes table (6), 25% hi, 17.5 pitch in good condition. | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X' | 1.0 | yes | 10 | 0.5 | 1 |

Table 41: Selected Benchmark Risers Examples

| File Name | Description | Units (flag) | Calculation Option | Structural Model | | | | SN-Curve | SCF | Suppression | Beta Iteration | Traveling Wave Excitation Ratio | Non-Orthogonal Damping |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Code | Type | B.C | Tension | | | | | | |
| benchmark_ndp_bare | NDP38m model test riser bare shear current | SI (0) | 1 | 1 | beam | pinned-pinned | varying | DNV F2 (single slope) | 1.0 | no | 10 | 0.5 | 1 |
| benchmark_ndp_strake | NDP38m model test riser with 50% strake coverage benchmark case | SI (0) | 1 | 1 | beam | pinned-pinned | varying | DNV F2 (single slope) | 1.0 | yes | 10 | 0.5 | 1 |
| benchmark_miami2_bare | Long flexible DeepStar field test riser - bare | English (1) | 1 | 1 | beam | pinned-pinned | varying | API-X' | 1.0 | no | 10 | 0.5 | 1 |

Table 42: Jumper VIV Modeling Examples

| File Name | Description | Units (flag) | Calculation Option | Structural Model | | | | SN-Curve | SCF | Suppression | Beta Iteration | Damping Coeff. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Code | Type | B.C | Tension | | | | | |
| BareJumper_CF_OP [2] | Cross flow VIV, out-of-plane modes on a bare M jumper | SI (0) | 3 OutofPlaneModes | 999 | N/A | N/A | N/A | DNV D with CP | 1.0 | no | 0 | See Table 43 |
| BareJumper_CF_IP [2] | Cross flow VIV, in-plane modes on a bare M jumper | SI (0) | 3 InPlaneModes | 999 | N/A | N/A | N/A | DNV D with CP | 1.0 | no | 0 | See Table 43 |
| BareJumper_IN_OP [2] | In-line VIV, out-of-plane modes on a bare M jumper | SI (0) | 3 OutofPlaneModes | 999 | N/A | N/A | N/A | DNV D with CP | 1.0 | no | 0 | See Table 43 |
| BareJumper_IN_IP [2] | In-line VIV, in-plane modes on a bare M jumper | SI (0) | 3 InPlaneModes | 999 | N/A | N/A | N/A | DNV D with CP | 1.0 | no | 0 | See Table 43 |

Notes:
1. The axial damping term is experimental and remains to be calibrated by comparison to model tests.
2. This example file cannot be run when using an Academic License.

The regions that are horizontal for the jumper examples are between the following x/L values;

- x/L = 0.034 to x/L = 0.29;
- x/L = 0.342 to x/L = 0.78; and
- x/L = 0.845 to x/L = 0.95

Table 43: SHEAR7 Parameters Used For Jumper Examples

| Section Type | Jumper Region | Added Mass | Strouhal Number | Bandwidth | Lift Coefficient Table (CL Table) | Damping Coefficient | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | DampCoeff 0 | DampCoeff 1 | DampCoeff 2 | DampCoeff 3 | DampCoeff 4 |
| Cross Flow VIV Out-of-Plane | | | | | | | | | | |
| Vertical | Bare | 1 | 0.18 | 0.40 | 1 | 1 | 0.20 | 0.18 | 0.20 | 0 |
| Horizontal[1] | Bare | 1 | 0.18 | 0.40 | 1 | 0 | 0 | 0 | 0 | 0 |
| Cross Flow VIV In-plane | | | | | | | | | | |
| All | Bare | 1 | 0.18 | 0.40 | 1 | 1 | 0.20 | 0.18 | 0.20 | 0 |
| Inline VIV Out-of-Plane | | | | | | | | | | |
| All | Bare | 1 | 0.33 | 1.16 | 7 | 1 | 0.20 | 0.18 | 0.20 | 0 |
| Inline VIV In-Plane | | | | | | | | | | |
| Vertical | Bare | 1 | 0.33 | 1.16 | 7 | 1 | 0.20 | 0.18 | 0.20 | 0 |
| Horizontal[1] | Bare | 1 | 0.33 | 1.16 | 7 | 0 | 0 | 0 | 0 | 0 |

Notes:
1. The joints are included as horizontal sections

# 10 MODELING GUIDANCE

- If parameters are missing from the input configuration file SHEAR7 provides the user with the parameters it has failed to read. If unsure use the supplied *.s7*dat conversion program (Section 8) which will utilize the default values listed in Appendix A.

- Caution: Do not attempt to model too much detail in the zones: The zone capability in SHEAR7 should not be used to include small structural details of the riser, such as the BOP, the LMRP, the flex joint and the slip joint. It is not yet known how to hydrodynamically model many of these structures and SHEAR7 does not model them dynamically. Hence, including such details in a SHEAR7 model only increases the likelihood of modeling and computation errors. A suggested approach is to include such structural details in the FEM calculations used to compute the mode shapes and natural frequencies of the structure. Only include zones in SHEAR7 that are needed to model the important hydrodynamics. Typically, zones should be used to distinguish between long segments, which have significant changes in diameter, damping, or require different lift coefficient tables, such as zones with strakes or fairings. Very short length features, which will not significantly alter the overall hydrodynamics, should be neglected.

- Use Caution when using the internal eigen solver and multiple structural zones. The multiple zone feature in SHEAR7 may not give accurate natural frequency and mode shape information, especially at high mode number, when sudden changes in mass or stiffness occur in the riser model. This is because SHEAR7's internal eigen solver uses the WKB approximation, which assumes slowly varying properties, such as mass per unit length and moment of inertia, to estimate the natural frequencies and mode shapes. For example, buoyancy modules cause large jumps in mass and sudden changes in effective tension. Wave reflections at these boundaries are not modeled correctly by the WKB method. It is recommended that the natural frequencies and mode shapes of complex structures be computed using an external finite element program. The results can then be used to prepare a common.s7mds file for use with calculation Option 2, or any .mds file for use with calculation Option 3.

- When an externally generated .mds file option is used, the tension distribution, obtained from the structural zone data, is not used in the SHEAR7 computations. However, the mass distribution does influence the modal mass computation, which in turn is used to compute damping ratio. Similarly, the hydrodynamic diameter distribution influences the hydrodynamic lift and damping calculations. These lift and damping values are used in computing the modal response amplitude.

- A complete table of SHEAR7 error messages is listed in Appendix C.

# APPENDIX A DEFAULT SHEAR7 PARAMETERS

## A.1 DEFAULT SHEAR7 PARAMETERS

The experimental results in laboratory and field tests have been used to provide a set of default parameters used by SHEAR7. The default parameters are provided in Table A1. However it should be noted that the default parameters have been determined with the following limitation:

- The published experimental results have been obtained from mostly low Reynolds number testing. Exceptions to this are the high Reynolds CL table and the high Reynolds LGS CL table which originate from supercritical Reynolds number tests and a subset of the 38m SHELL tests that used a rough surface for the riser model.
- For straked risers, the experiments have a specific geometry (strake height = 25% of diameter; Strake pitch = 17.5 diameters).
- All the straked experiments considered the straked region clean (do not have marine fouling) and are undamaged.
- Future research is still needed to improve the ability to model fairings.
- Typical response of a riser with partial strake/fairings coverage, will be driven mostly by the unprotected region, with the straked region providing damping.
- The default value for the beta control number is 4; however, if the response is not converging this value can be increased up to 10.
- The default value for the beta control number is 10. Most cases will converge much faster, at typically 4-5 iterations. SHEAR7 will stop iterating if it determines that the solution has converged or if the program reaches the maximum number of iterations set by the user, whichever occurs first. If the examination of the .s7out file shows that the distributed amplitude iterations (i.e. beta iterations) have not converged, then the beta control number can be increased to higher values.
- The beta function is generally only important for VIV excitation of high mode numbers (Mode 5 and above), therefore, for efficient run times, the beta control number should be set to zero if modeling the following structures:
    - rigid subsea jumpers with low mode number excitation,
    - pipeline response with low mode number excitation,
    - in-line response at low mode number excitation.
- The non-orthogonal damping correction can greatly improve the VIV modeling capabilities. This is especially true for VIV responses exciting high mode numbers or cylinders with non-uniform hydrodynamic properties along their length (e.g. partial strake coverage, etc.). The non-orthogonal damping correction should always be switched on, unless one is intentionally trying to mimic the VIV modeling approach in older versions of SHEAR7.
- The Higher Harmonics amplification factor and threshold can be important when modeling systems that result in Higher mode number excitation. When using the Higher Harmonics feature, the default threshold value is 0.3 and the default Higher Harmonics amplification

factor is 2.00. Otherwise Higher Harmonics amplification can be deactivated by setting the amplification factor, α, to 0.0.

- It is noted that the axial flow damping capability now available since SHEAR7 version 4.9 remains as an experimental feature and is yet to be fully verified. Further testing has been planned for calibration against other model tests and field data. Although Axial Damping Coefficients are available from regulations associated with offshore analysis, these have not been verified for VIV predictions in SHEAR7. It is recommended that users set this parameter to 0.0 for their analyses.

Table A1: SHEAR7 Default Parameters For Risers/Pipes[10]

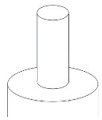
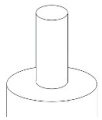
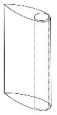
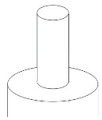
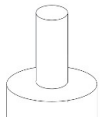
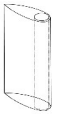
| Property | | Riser/Pipe Region | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cross-Flow | | | | In-line | | | |
| | | Bare Or Bare/Buoy  | Strakes[6]  | Fairings  | LGS Low-Re 3.8%/ High-Re 3.8%/ High-Re 6.2%[3]  | Bare Or Bare/Buoy  | Strakes[6]  | Fairings  | LGS 3.8%/6.2%[3]  |
| Added Mass | | 1.0 | 2.0 | 2.0 | 1.0 | 1.0 | 2.0 | 2.0 | 1 |
| Strouhal Number | | 0.18 | 0.10 | 0.10 | 0.185 / 0.18 / 0.18 | 0.33 | 0.10 | 0.10 | 0.33 |
| Bandwidth | | 0.40 | 0.25 | 0.00[5] | 0.5 | 1.15 | 0.25 | 0.00[5] | 1.16 |
| Conservative CL Table (ideal for preliminary design investigations, etc.) | | 1 | 5 | 5 | 12 / 11 / 10 | 7 | 5 | 5 | - - / 9 |
| Less Conservative CL Table (for detailed design investigations, life extension studies, etc, where the knowledgeable user exercises great care on choosing the appropriate and most relevant hydrodynamic parameters for the structure being modelled) | | 4 (for supercritical Re [8]) | 6[9] | 6[9] | 12 / 11 / 10 | 8 | 6[9] | 6[9] | -- / 9 |
| Beta Control Number | | 10 | | | | 10 | | | |
| Damping Values[7] | Reynolds Number Still Water | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| | A/D Still Water | 0.20 | 0.40 | 0.40 | 0.25 | 0.20 | 0.20 | 0.20 | 0.20 |
| | Low $V_R$ Regions | 0.18 | 0.50 | 0.50 | 0.15 | 0.18 | 0.18 | 0.18 | 0.18 |
| | High $V_R$ Regions | 0.20 | 0.20 | 0.40 | 0.60 | 0.20 | 0.20 | 0.20 | 0.20 |
| | Axial Flow Regions | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Power Ratio Cutoff | | 0.2 | | | | 0.2 | | | |
| Primary Zone Amplitude Limit | | 0.65 | | | | 0.65 | | | |
| Lift Coefficient Reduction Factor | | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| Power Ratio Exponent | | 1 | | | | 1 | | | |
| Non-Orthogonal Damping | | 1 | | | | 1 | | | |
| Traveling Wave Excitation Ratio | | 0.5 | | | | 0.5 | | | |
| Higher Harmonics Threshold-if req'd | | 0.3 | | | | N/A | | | |
| Higher Harmonics Factor-if req'd | | 2.00 | | | | N/A | | | |

Table A1: SHEAR7 Default Parameters For Risers/Pipes[10]

| Property | Riser/Pipe Region | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cross-Flow | | | | In-line | | | |
| | Bare Or Bare/Buoy  | Strakes[6]  | Fairings  | LGS Low-Re 3.8%/ High-Re 3.8%/ High-Re 6.2%[3]  | Bare Or Bare/Buoy  | Strakes[6]  | Fairings  | LGS 3.8%/6.2%[3]  |

Notes:

1. The default parameters provided in this table have been largely developed from the results of sub-critical and critical Reynolds number testing.
2. The parameters for fairings have been developed for a specific set of fairings. These fairings were clean, undamaged, had no marine growth and were free to rotate. Any analysis of long term performance should be cognizant of these aspects.
3. LGS (Longitudinal Grooved Suppression) is a low drag, moderately low VIV suppression profile. See Appendix J . LGS modeling parameters are based on the outermost diameter being the hydrodynamic reference diameter. Values are provided for 3.8%/6.2% groove/OD depth. Sub-crticial Re tests extended up to Re max ~1.3e4. High Re test covered the range 5.5e5 < Re < 1.6e6.
4. This represents a perfect high chord length fairing. There are many different fairing shapes and the user should seek to obtain the specific fairing response data – this statement applies to all profiles, not just fairings.
5. It is suggested that a sensitivity study be performed with small positive bandwidth values.
6. Helical strake parameters are based on the root diameter being the hydrodynamic reference diameter.
7. A conservative structural damping value is 0.003 (0.3%), where drilling risers with buoyancy are considered, benchmarking has shown close agreement can be obtained with specific modeling parameters (OMAE 2023-10400) and a structural damping closer to 0.01 (1%).
8. The parameters for super-critical Reynolds numbers are based on the work described in OMAE2023-104900: “A report from the drilling riser VIV and wellhead fatigue JIP: Full-scale drilling riser VIV measurements and comparisons with predictions” Resvanis et. al.
9. For ideal, clean (no marine growth), undamaged strakes based on 25% high, 17.5 pitch ratio. Please use with caution.
10. All the parameters in this table assume that the structural zones defined have a sufficiently large aspect ratio (at minimum L/D>20, ideally L/D>40). For shorter aspect ratios, the 3D effects are non-negligible and detailed experimental investigations are needed to determine the appropriate hydrodynamic parameters.

For non-conservative predictions of super-critical Reynolds number bare or bare/buoyancy risers, the set of default parameters shown in Table A2 are suggested[1].

Table A2: SHEAR7 Default Parameters For Predictions Of Super-critical Reynolds Number Bare Or Bare/buoyancy Risers

| Parameter | Non-conservative Predictions Of Super-critical Reynolds Number Bare Or Bare/buoyancy Risers |
|---|---|
| CL table | Table #4<br>(distributed from SHEAR7 v5.0) |
| dVr | 0.4 |
| St | 0.185 |
| Ca | 1.0 |
| Hydrodynamic damping coefficients | 0.2, 0.18, 0.2 |
| Power cut-off value | 0.20 |
| PZAL | 0.65 |

1 OMAE2023-104900 “A report from the drilling riser viv and wellhead fatigue JIP: Full-scale drilling riser viv measurements and comparisons with predictions” Resvanis et. al.

# APPENDIX B UNDERSTANDING LIFT COEFFICIENT

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## B.1 UNDERSTANDING LIFT CURVE COEFFICIENTS SINCE VERSIONS 4.3

SHEAR7 versions since 4.3 have included many improvements and new features that enhance the computational accuracy and versatility of the program. The major improvements concern the way SHEAR7 assigns a lift coefficient to each point along the riser. Other changes deal with some of the initial power calculations made by SHEAR7 and improving SHEAR7's ability to accurately model situations involving high mode number excitation and the ability to directly model strakes and fairings without having to use the lift coefficient reduction factor. The following document details the changes and added features in SHEAR7 versions since 4.5, and demonstrates how a user of SHEAR7 4.4 can easily become proficient at using the current version of SHEAR7.

Lift Coefficient Methodology in versions since 4.3. The value of the lift coefficient (designated CL) in versions since 4.3 is a function of the value of the non-dimensional response amplitude (A/D).

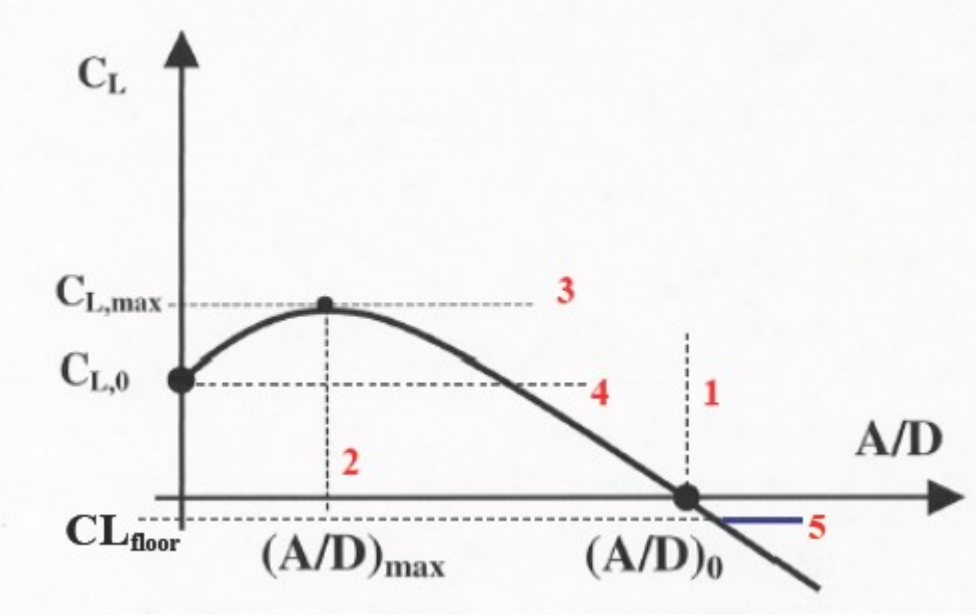


Figure B-1: SHEAR7 defines a smoothed lift coefficient curve by fitting two parabolas to three defined by four user-specified values.

However, rather than using a piecewise linear table (as done in version 4.2), versions since 4.3 generate a function-based, smooth lift coefficient vs. A/D curve, as shown in Figure B-1.

A property of the lift coefficient tables are that for each reduced velocity (implemented in the CL tables as a normalized reduced frequency) there is a value of the response amplitude at which the lift coefficient becomes negative and provides damping.

Since version 4.4 a fifth parameter $C_{L,floor}$ is added that limits the maximum negative value of the lift coefficient. In version 4.3 this value was set at -1.0. In versions since 4.5, the user must specify in the common.s7cl table the desired value of the maximum negative lift coefficient. This fifth parameter is called $C_{L,floor}$. This parameter can be quite important in strake modeling. Tables 3 through 6 are examples. Two new tables appeared in version 4.7

### B.1.1 Some key points regarding the lift coefficient curves:

- Lift Coefficient ($C_L$) is a function of non-dimensional response amplitude (A/D) and reduced velocity.
- Instead of having a look up table, $C_L$ is determined from a smooth curve constructed by fitting two parabolas through three points (as per Figure B-1), defined by the following four values:

1. $(A/D)_0$ – The value of A/D when $C_L = 0$
2. $(A/D)_{max}$ – The value of A/D when $C_L$ is at its maximum
3. $C_{L,max}$ – The maximum value of $C_L$
4. $C_{L,0}$ – The value of $C_L$ when A/D = 0
5. $C_{L,floor}$ – The minimum value of $C_L$ (used in SHEAR7 since version 4.4). This limits the minimum allowed $C_L$ value to a floor shown as 5 in the plot.

In SHEAR7 version 4.3 $C_{L,floor}$ was not described because it was set at $C_{L,floor}$ = -1.0 internally by the program.

- Using this method, $C_L$ curves are easily defined; thus, multiple curves can be used to make $C_L$ a function of the non-dimensional frequency ratio, a quantity related to the inverse of the reduced velocity.
- The six values are specified in an input file called *'common.s7cl'* that contains the following sets of curves:
  - $C_L$ table1:

    A single curve, independent of frequency ratio, which approximates the SHEAR7 v4.2 lookup table.
  - $C_L$ table2:

    A non-conservative, experimental data fit, which is a three dimensional lift coefficient curve that varies based on A/D and frequency ratio.
  - $C_L$ table3:

    This is a dummy table.
  - $C_L$ table4:

    Fit to the 2015 High Reynolds number data
  - $C_L$ table5:

    A conservative model of strakes that can be used with strakes designs other than those specified above. This model is more conservative than $C_L$ table4 or $C_L$ table6.
  - $C_L$ table6:

This is reserved for a table for ideal, clean (no marine growth), undamaged strakes based on 25% high, 17.5 pitch ratio. Please use with caution.

- $C_L$ table7:

  A very conservative in-line excitation model

- $C_L$ table8:

  An in-line excitation model

- $C_L$ table9:

  An In-line LGS 6.2% model for risers, rigid spools and pipes for sub-critical Reynolds number

- $C_L$ table10:

  A Cross-Flow LGS 6.2% model for risers, rigid spools and pipes for post-critical Reynolds number

- $C_L$ table11:

  Cross-Flow LGS 3.8% model for drilling riser buoyancy for *post*-critical Reynolds number

- $C_L$ table12:

  Cross-Flow LGS 3.8% model for drilling riser buoyancy for *sub*-critical Reynolds number

- $C_L$ table13:

  30% marine growth for strakes at subcritical Reynolds numbers

- $C_L$ table14:

  60% marine growth for strakes at subcritical Reynolds numbers

- $C_L$ table15:

  30% marine growth for strakes at supercritical Reynolds numbers

- $C_L$ table16:

  60% marine growth for strakes at supercritical Reynolds numbers

- The user can define multiple structural zones in a *.s7*dat file, and assign a different $C_L$ table for each region.

### B.1.2 Some key points regarding the *common.s7cl* file:

- Figure 2 gives an example of the data contained in the *common.s7cl* file.
- The *common.s7cl* file must be in the same directory as the SHEAR7 program.

- The first block of the .s7cl file gives the number of $C_L$ tables contained in the file. Each ensuing block contains the data for one $C_L$ table.

- Within a $C_L$ table block, the first line indicates the number of non-dimensional frequency ratio points for which the $C_L$ curves will be defined. The non-dimensional frequency, $f_n / f_{vo}$, is the ratio of the vibration frequency of the riser, $f_n$, to the most favourable local shedding frequency, $f_{vo}$. The most favourable shedding frequency is simply the selected Strouhal number times the local flow speed, divided by diameter. The non-dimensional frequency is given in Equation 5. At the centre of the power-in region the natural frequency and the most favourable shedding frequency are equal.

$$\frac{f_n}{f_{vo}(z)} = \frac{f_n}{S_t U(z)/D} \qquad \text{Equation 5}$$

- For subcritical Reynolds numbers, the most favourable reduced velocity is approximately 5.88, which has an inverse value of 0.17. In SHEAR7 the most favourable shedding frequency is computed from a user-provided Strouhal number. The Strouhal number is specified by the user for each structural zone. It can be in the form of a specific number or taken from a Reynolds number dependent table. In either case at every location on the riser there is a most favourable vortex shedding frequency, $f_{vo}(z)$, which may be computed using the Strouhal number, the local flow velocity and the diameter. The lift coefficient table is tabulated in terms of the ratio of the natural frequency in each power-in zone to the most favourable shedding frequency at every node inside the power-in region according to the above equation.

- This ratio has a maximum value of 1.0 at the value the user wants to be the centre of a lock-in range. This is usually at or near the peak in the lift coefficient curve.

- The $C_L$ table block contains five columns, giving the following data:

  - <u>Column 1:</u>

    The non-dimensional frequency ratio, $f_n / f_{vo}$, which SHEAR7 uses to automatically centre the power-in region at or near the peak lift coefficient in the CL table, which is defined at $f_n / f_{vo}(z) = 1.0$.

  - $f_n / f_{vo}(z)$ is shown in the equation above, where fn is the frequency of the mode being considered and fvo(z) is the local Strouhal frequency. $f_n / f_{vo}$ does not provide any information about the effect of mass ratio on natural frequency, but reflects only the ability of the fluid to synchronize with the motion of the cylinder.

  - In a sheared flow the local Strouhal frequency, $f_{vo}$, varies with the flow velocity, but each mode has only one natural frequency $f_n$. When the parameter $f_n / f_{vo} = 1.0$, the vibration frequency matches the Strouhal frequency. Looking at a particular power-in region for a given mode and assuming a constant St number, it is seen that for the faster flow region the local Strouhal frequency will be larger than the natural frequency, and thus $f_n / f_{vo} < 1.0$. Similarly, for the slower flow region $f_n / f_{vo} > 1.0$. As long as the peak lift coefficient in

the CL table is centered on $f_n / f_{vo}$=1.0, then the peak lift coefficient will automatically be at the center of the power-in region, whatever the Strouhal frequency, or Strouhal number that has been specified in the input data.

- Column 2 -5:

  Each column (2-5) is one of the four values defined in Figure 1 that give SHEAR7 the necessary information to construct the lift coefficient curves. Column 2 corresponds to the normalized amplitude corresponding to zero lift coefficient, column 3 to the amplitude at the maximum lift coefficient, column 4 to the maximum lift coefficient, and column 5 to the lift coefficient at zero amplitude.

- Column 6:

  Each column (6) defines the straight, horizontal line segment truncating the parabolic approximation of CL as the function of (A/D). It is shown in blue on Figure 1. It is the most negative allowed Cl.

- A single-line CL table (such as tables 1, 3, 5 and 6 in the *common.s7cl* file which is provided) indicates a single lift coefficient vs. A/D curve that is applied at all frequency ratio values. This represents a lift coefficient model that is independent of the frequency ratio, and thus looks like a constant ridge in 3 dimensions.

# APPENDIX C SHEAR7 ERROR MESSAGES

Table C1: SHEAR7 Error Messages

| Warning ID/Code Reference | Message Provided To User | SHEAR7 Halted (Yes/No) | File Output | Description |
|---|---|---|---|---|
| 1 | RUNTIME ERROR:<br>You should use 0 (SI) or 1 (English)<br>to choose a unit system. | Yes | .s7out | SHEAR7 supports two different unit systems; SI based units and English based units. The 1st line of BLOCK 1 defines which unit set the user has used through the input *.s7*dat file. The provided input *.s7*dat file has not specified either a zero (0) or one (1) on this line, as required. See Section 5.2 for the required units of each parameter in the input *.s7*dat file. |
| 4 | RUNTIME ERROR:<br>The starting response location must be less than the ending location in your input. | Yes | .s7out | The end response location is smaller than the start response location specified in the 2nd line of the BLOCK 5 of input *.s7*dat file. See Section 5.6.2 for explanation of these terms. |
| 5 | RUNTIME ERROR:<br>Incorrect step size for response location. | Yes | .s7out | The step size specified in the 2nd line of BLOCK 5 in input *.s7*dat file is greater than the difference between the specified start and end response locations. See Section 5.6.2 for explanation of these terms. |
| 6 | RUNTIME ERROR:<br>Input step size is less than spatial resolution. It has been reset in the program. | No | .s7out | The step size specified in the 2nd line of BLOCK 5 in input *.s7*dat file is less than the spatial resolution specified in line 3 of BLOCK 2 in input *.s7*dat file. The user should increase the response step size. |
| 7 | RUNTIME ERROR:<br>Flag to choose calculation option must be 0, 1, 2 or 3 | Yes | .s7out | The calculation option determines if the .mds file will be calculated by SHEAR7 using inbuilt solvers of if proved by the user. The 1st line of BLOCK 5 in input *.s7*dat file needs to be specified as either 0, 1, 2, or 3. See Section 5.6.1 for further description of the options. |
| 8 | RUNTIME ERROR:<br>To specify a current profile, x/L must be in ascending order. Your input is invalid. | Yes | .s7out | The current profile in BLOCK 3 of the input *.s7*dat file has been specified incorrectly. The first column in BLOCK 3 must be in ascending order. See Section 5.4.2 for the required format of the current profile. |
| 9 | RUNTIME ERROR:<br>The annual probability of occurrence should be no greater than 1.0. Your input is invalid. | Yes | .s7out | The 2nd value in the 1st line of BLOCK 3 in input *.s7*dat file has been specified incorrectly. See Section 5.4.1 for further description of the current profile parameters. |

Table C1: SHEAR7 Error Messages

| Warning ID/Code Reference | Message Provided To User | SHEAR7 Halted (Yes/No) | File Output | Description |
|---|---|---|---|---|
| 10 | NOTICE:<br>Program indicates that there is negative effective tension at node: | No | .s7out | This informs the user that SHEAR7 has determined some nodes to have negative effective tension. If the user did not expect any negative tension they should review the input *.s7*dat file used. |
| 11 | RUNTIME ERROR:<br>The input number of modes:<br>[number of input modes]<br>exceeds the program capacity:<br>[program capacity] | Yes | .s7out | SHEAR7 has an internal calculation limit of 1000 modes. If an .mds file has greater than this number the program will not run. The user should decrease the number of modes to below 1000. |
| 13 | RUNTIME ERROR:<br>The input # of nodes are not equal (as required).<br>In the *.s7*dat file, you input: [number of *.s7*dat nodes]<br>In the common.mds file, you input: [number of .mds nodes] | Yes | .s7out | The number of nodes stated in the user supplied .mds file needs to be one (1) greater than the number of segments specified in the input *.s7*dat file. |
| 14 | RUNTIME ERROR:<br>The maximum MDS mode number is:<br>The maximum potentially excited mode number is:<br>The modes supplied are not sufficient.<br>Modes up to at least 4.0 times the maximum potentially excited mode number should be supplied. | Yes | .s7out | In order to predict the VIV response of a system, SHEAR7 requires a modal space that extends beyond the maximum potentially excited mode number of the system by 4.0 times. This is used to determine the superposition of associated modes. The user supplied .mds file will require a greater number of modes to be included. |
| 16 | NOTICE:<br>No VIV has been predicted.<br>The maximum shedding frequency is below the fundamental natural frequency band.<br>The program predicts that VIV may not occur.<br>The minimum excitation frequency is:<br>The maximum excitation frequency is:<br>The first natural frequency is:<br><br>The above frequencies are in rad/s | Yes | .s7out | Based on the modal parameters and current profile provided, no VIV was predicted as the first natural frequency of the system is above that of the maximum excitation frequency. |
| 17 | NOTICE:<br>No VIV has been predicted. This may be due to a very weak power-in and is insufficient to result in VIV. | Yes | .s7out | Based on the input parameters specified, no VIV was predicted. |
| 18 | RUNTIME ERROR:<br>zero modal input power. check input data. | Yes | .s7out | Based on the input parameters there is no modal power predicted, no VIV was predicted. |

Table C1: SHEAR7 Error Messages

| Warning ID/Code Reference | Message Provided To User | SHEAR7 Halted (Yes/No) | File Output | Description |
|---|---|---|---|---|
| 19 | RUNTIME ERROR:<br>mode shape calculation incorrect.<br>zero mode shape and curvature. | Yes | .s7out | The inbuilt modal calculation has been unable to generate mode shapes and curvatures. Consider reviewing the input parameters or generating the mode file (.mds) in an external program. |
| 20 | RUNTIME ERROR:<br>The maximum mode number is greater than the program-allowed:<br>If you want to run this case, you should change the program-allowed maximum. | Yes | .s7out | The inbuilt modal calculation has generated more modes than the SHEAR7 mode count limit. Please consult with the SHEAR7 support team. |
| 21 | RUNTIME ERROR:<br>You have requested more CL data than than is available in common.CL | Yes | .s7out | The CL table specified for at least one (1) of the zones in the input *.s7*dat file (as per Section 5.3.9.5) does not exist in the provided common.CL file. Please check both the CL tables specified in the input *.s7*dat file and the common.CL file that is being used. |
| 22 | RUNTIME ERROR:<br>You have stress-cycle data in non-increasing stress order | Yes | .s7out | Please see Section 5.5 for the required format of the S-N Curve data. |
| 23 | RUNTIME ERROR:<br>Not a valid Strouhal number code to choose a unit system. | Yes | .s7out | Strouhal number codes are no longer supported in SHEAR7. See Section 5.3.9.5 for information on Strouhal number. |
| 24 | RUNTIME ERROR:<br>The predicted dominant inline mode number is Mode 3 or higher.<br>Cross-flow response prediction models should generally be used to estimate fatigue, which is assumed to be spread evenly around the circumference, when the reduced velocity is high enough to excite Cross-flow Mode 1 and above. | Yes | .s7out | Cross-flow response prediction models should generally be used to estimate fatigue, which is assumed to be spread evenly around the circumference, when the reduced velocity is high enough to excite Cross-flow Mode 1 and above. |
| 25 | RUNTIME ERROR:<br>The number of spatial segments is less than the estimated minimum number required by SHEAR7.<br>Number of spatial segments:<br>Required number of spatial segments: | Yes | .s7out | SHEAR7 requires a minimum spatial resolution based on the maximum excited mode number. To continue running this case the number of spatial segments would need to be increased. |

Table C1: SHEAR7 Error Messages

| Warning ID/Code Reference | Message Provided To User | SHEAR7 Halted (Yes/No) | File Output | Description |
|---|---|---|---|---|
| 26 | RUNTIME ERROR:<br>The zone size from dat files is less than the length of the length of segment at this location. | Yes | .s7out | The length of at least one of the zones is shorter than the segmentation length. Potential resolutions are:<br>Increasing the length of the offending zone(s) to be greater than the segmentation length; or<br>Decreasing the segmentation length by increasing the number of segments. |
| 27 | RUNTIME ERROR:<br>No segments defined in mds file have been assigned to zone defined in dat file. | Yes | .s7out | There is a zone that has not had its properties applied to any zone. This is due to the zone size being too small or the segmentation too coarse. Potential resolutions are:<br>Increasing the length of the zone(s) to be greater than the segmentation length; or<br>Decreasing the segmentation length by increasing the number of segments. |
| 28 | RUNTIME ERROR:<br>Local SCF has overwritten previous Local SCF Check Local SCF x/L positions in dat file. | Yes | .s7out | Local SCFs can only be applied to nodes, therefore SHEAR7 will move the Local SCF position to be at the closest node. If the x/L position of two or more Local SCFs result in SHEAR7 moving them to the same node this error is raised. Two potential resolutions are:<br>Adjusting the specified x/L position of the Local SCFs so that they are on nodal positions; or<br>Decreasing the segmentation length by increasing the number of segments. |
| 29 | RUNTIME ERROR:<br>Mode shape values in the user supplied .mds file must be normalised. Please check the .mds file | Yes | .s7out | The mode shapes specified in the user supplied .mds file must be normalised to unity. The required format of the .mds file is specified in Section 7.3. |
| 30 | Preliminary power calculations indicate that no VIV excitation will occur. Either there is too little power-in for any mode or the excitation frequencies fall in between the natural frequencies. Program stopped. | Yes | .s7out | Based on the input parameters there is no VIV predicted. |
| 31 | RUNTIME ERROR:<br>Unable to find a convergent solution to the response for standing wave excitation. | Yes | .s7out | A convergent solution cannot be found for standing wave excitation. Please consult with the SHEAR7 support team. |

Table C1: SHEAR7 Error Messages

| Warning ID/Code Reference | Message Provided To User | SHEAR7 Halted (Yes/No) | File Output | Description |
|---|---|---|---|---|
| 32 | RUNTIME ERROR:<br>Unable to find a convergent solution to the response for traveling wave excitation. | Yes | .s7out | A convergent solution cannot be found for traveling wave excitation. Please consult with the SHEAR7 support team. |
| 50 | INPUT ERROR:<br>Flag for non-orthogonal damping must be 0 or 1. | Yes | .s7out | Please see Section 5.6.20 for the required format of the non-orthogonal damping flag. |
| 51 | INPUT ERROR:<br>Flag for stick-slip damping must be 0, 1 or 2. | Yes | .s7out | |
| 52 | INPUT ERROR:<br>Tolerance for stick-slip damping must be greater than 0.0. | Yes | .s7out | |
| 53 | INPUT ERROR:<br>Common.s7cat file must be used when using stick-slip damping. | Yes | .s7out | |
| 54 | INPUT ERROR:'<br>Error with .s7inhyst file. | Yes | .s7out | |
| 55 | INPUT ERROR:'<br>Inhyst custom filename must be provided when using flag of 2. | Yes | .s7out | |
| 56 | INPUT ERROR:'<br>Must use stick-slip damping to generate .zeta-hyst out file. | Yes | .s7out | |
| 61 | LICENSE ERROR:<br>Academic License only allows 8.00E+02m Structural Length<br><br>This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program. | Yes | .s7out | Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations. |
| 61 | LICENSE ERROR:<br>Academic license only allows 2.624E+03ft Structural Length<br><br>This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program. | Yes | .s7out | Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations. |
| 61 | LICENSE ERROR:<br>Academic license only allows 1 S-N Curve<br><br>This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program. | Yes | .s7out | Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations. |

Table C1: SHEAR7 Error Messages

| Warning ID/Code Reference | Message Provided To User | SHEAR7 Halted (Yes/No) | File Output | Description |
|---|---|---|---|---|
| 61 | LICENSE ERROR:<br>Academic license only allows 1 S-N Curve Segment<br><br>This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program. | Yes | .s7out | Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations. |
| 61 | LICENSE ERROR:<br>Academic license only allows 1 Local SCF<br><br>This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program. | Yes | .s7out | Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations. |
| 70 | INPUT ERROR:<br>Unable to read common.s7cat file. | Yes | .s7out | This error occurs when the file cannot be found. |
| 72 | INPUT ERROR:<br>Common.s7cat read error. | Yes | .s7out | An error has occurred while reading the common.s7cat file. |
| 73 | INPUT ERROR:<br>Common.s7cat read error (must define static mean curvature). | Yes | .s7out | An error has occurred while reading the common.s7cat file. |
| 74 | INPUT ERROR:<br>Invalid input file name | Yes | .s7out | This error occurs when a file cannot be found that matches the input file name. |
| 75 | INPUT ERROR:<br>Time history generation is not currently enabled when using the zero-crossing frequency fatigue option. | Yes | .s7out | This error occurs when both the flag for stress time history and the flag for calculating fatigue with zero-crossing method are enabled. |
| 76 | INPUT ERROR:<br>Values in the .s7mds file must not be NaN. Please check the .s7mds file | Yes | .s7out | This error occurs when there's a NaN value in the .s7mds file used. If using the internal SHEAR7 natural frequencies and mode shapes solver, this may be due to the model being too complex. |
| 77 | INPUT ERROR:<br>Traveling wave excitation ratio must be between 0 and 1 inclusive | Yes | .s7out | This error occurs when the traveling wave excitation ratio is larger than 1 or less than 0. |
| 78 | INPUT ERROR:<br>Traveling wave excitation ratio cannot be greater than 0 when distributed beta is not enabled. The program stops. | Yes | .s7out | This error occurs when the traveling wave excitation ratio is greater than 0 and distributed beta is not enabled. |
| 80 | HASP key not found with status: | Yes | None | No SHEAR7 license or license dongle was found. Ensure a SHEAR7 license is available or a license dongle is connected to the computer. |
| 81 | HASP key Logout failed with status: | Yes | None | Unable to disconnect from the license or license dongle. Ensure the dongle remains connected until SHAER7 completes the analysis. |

Table C1: SHEAR7 Error Messages

| Warning ID/Code Reference | Message Provided To User | SHEAR7 Halted (Yes/No) | File Output | Description |
|---|---|---|---|---|
| 82 | HASP Failed with status: | Yes | None | Unable to receive information from the license or license dongle. |
| 83 | HASP Failed with status: | Yes | None | Unable to receive information from the license or license dongle. |
| 84 | HASP Failed with status: | Yes | None | Unable to receive information from the license or license dongle. |
| 101 | Input file not found. Exiting.... | Yes | None | A file with the name specified has not been found. Check that the filename is correct. Avoid using spaces in SHEAR7 input filenames. |
| 102 | Wrong version of input file. Program stopped. | Yes | .s7out | The first line of the input file specifies the version number of the file. See section 5.1 for further details. |
| 103 | Common.CL file not found. Exiting.... | Yes | .s7out | The common.CL file should be in the same folder as the input file. See section 6.1 for additional information on execution options. |
| 104 | No negative currents can be specified.<br>Please correct in the *.s7dat. Program exits! | Yes | .s7out | Negative currents cannot be provided to SHEAR7. |
| 105 | ERROR, An ID. of a lift coefficient table CLtype specified that is greater than the maximum number nCLtype read from line 2 of the common.cl file.<br>Please correct in the *.s7dat or in the common.cl file. Program exits! | Yes | .s7out | The input file requests a CL table number bigger than what is in the provided common.CL file. |
| 106 | ERROR, An illegal, smaller than 1 ID. of a lift coefficient table CLtype specified. This program version does not support CLtype = 0 or smaller. Program exits! | Yes | .s7out | A CL table requested by the input file is less than 1. See section 5.3.9.5 for information on this input line. |
| 107 | ERROR, too many segments used in an S-N Curve definition. This program version allows a use of the maximum number of segments NSNL = 10<br>Please use less segments. Program exits! | Yes | .s7out | SHEAR7 only allows 10 segments to be defined for each S-N curve. See section 5.5.2 for additional information. |
| 108 | ERROR, S-N Curve I.D. No. repeated in the *.s7dat file, program exits!<br>ERROR, zone S-N Curve I.D. specified for an undefined curve, program exits!<br>ERROR, S-N Curve: non-consecutive I.D. numbering. Program exits! | Yes | .s7out | This identifies three errors related to the input S-N curves. |
| 110 | INPUT ERROR: Input error on line: line_num<br>Expected inputs: message<br>Fortran READ error: err | Yes | .s7out | This is the general error message template displayed when an input read error has occurred. This typically occurs when not enough values are provided on a particular line or when a float is used when an integer is required. |

Table C1: SHEAR7 Error Messages

| Warning ID/Code Reference | Message Provided To User | SHEAR7 Halted (Yes/No) | File Output | Description |
|---|---|---|---|---|
| 111 | INPUT ERROR: The outer diameter must be greater than the inner diameter.<br>Error in zone: zone_num | Yes | .s7out | See section 5.3.9.2 for information on the diameter specification line. |
| 112 | INPUT ERROR: There needs to be some non-zero current for VIV to occur. Please review the input file. | Yes | .s7out | SHEAR7 requires non-zero current for VIV prediction.<br>Note: This check is not performed if running calculation option zero (0). |

# APPENDIX D TUTORIAL / EXAMPLE

## D.1 EXAMPLES FROM TUTORIAL

The following describes a basic SHEAR7 example file to help the user get started. This example is also provided in the form of the 'basic_beam_3.s7dat' example file in the SHEAR7 program folder.

### D.1.1 Example Definition

The example details a tensioned beam (cylinder) with boundary rotational springs. All SHEAR7 parameters not defined in the tables below should be input as SHEAR7 default values as provided in this manual. The particulars from the beam are detailed in Table D1.

Table D1: Example Beam Particulars

| Dimension | Value |
|---|---|
| Length (ft) | 1500 |
| Cylinder Diameter (in) | 46.0 |
| Wall Thickness (in) | 2.0 |
| Hydrodynamic Diameter (in) | 84.0 |

Material Properties for the example beam are given in Table D2.

Table D2: Example Beam Material Properties

| Material Property | Value |
|---|---|
| Modulus of Elasticity (ksi) | 30,022.8 |
| Mass per unit length (lb/ft) | 2296.14 |
| Submerged weight per unit length (lb/ft) | 166.87 |

Stiffness properties for the example beam are given in Table D3.

Table D3: Stiffness Properties

| X/L Location | Stiffness (lbf-ft/rad) |
|---|---|
| 0 | 0.1e+7 |
| 1 | 0.1e+7 |

The current profile to be applied to the example beam is given in Table D4.

Table D4: Current Profile

| X/L Position On Beam | Current Velocity (ft/s) |
|---|---|
| 0.04 | 4.3 |
| 0.133 | 4.29 |
| 0.267 | 2.42 |
| 0.500 | 1.49 |
| 0.973 | 1.01 |
| 1.0 | 1.0 |

The following S-N curve in Figure D5 is to be used for the example.

Table D5: S-N Curve Properties

| Point | Stress Range (ksi) | Cycles To Failure |
|---|---|---|
| 1 | 4.01 | 0.1e+9 |
| 2 | 47 | 0.1e+5 |

Additional miscellaneous properties to be used in the example are listed in Table D6.

Table D6: Miscellaneous Properties

| Property | Value |
|---|---|
| Density of Fluid (lbf/ft$^3$) | 64.0 |
| Kinematic viscosity of the fluid (ft$^2$/s) | 0.000014 |
| Structural Damping | 0.003 |
| Number of segments | 200 |
| Cut-off stress range (ksi) | 0.00 |
| Global SCF | 1.0 |
| Traveling Wave Excitation Ratio | 0.5 |

The completed and example file is reproduced below for the example data provided.

SHEAR7 5.0: Data file for a tensioned beam with boundary rotational spring

File Name: basic_beam_3.*s7*dat nmodel = 6 pinned w/spring beam.

*** BLOCK 1. unit system ***

| | |
|---|---|
| 1 | flag for units |

*** BLOCK 2. structural and hydrodynamic data ***

| | |
|---|---|
| 6 | flag for structural model |
| 1500.000 | total length of the structure (ft) |
| 100 | number of spatial segments |
| 64.000 | volume weight of the fluid (lb/ft**3) |
| 0.0000140000 | kinematic viscosity of the fluid (ft**2/s) |
| 0.00300 | structural damping coefficient |
| 224809.0 | effective tension at origin (lbf) |
| 1 | no. of zones to define sectional property |
| 0.0000 1.0000 | zone start and end point in x/L |
| 84.00000 46.00000 42.00000 | hydro strength inside diameter(in) |
| 0.3233E+01 2296.140 166.870 | inertia(ft^4)mass(lb/ft) sbmg wt(lbf/ft) |
| 30022.8 1 | modulus of elasticity (ksi), S-N Curve I.D. No. |
| 0.5 0.18 1.0 1 | dVR, St code, Cl reduction factor, zoneCLtype |

1.0 1.0 0.20 0.18 0.20 0.00 Ca, DampCoeff0, DampCoeff1, DampCoeff2, DampCoeff3, DampCoeff4

*** BLOCK 3. current data ***

| | |
|---|---|
| 6 0.100E+01 200 | no. of profile data pts probability profile ID |
| 0.04 4.3000 | location (x/L) and velocity (ft/s) |
| 0.133 4.2900 | location (x/L) and velocity (ft/s) |
| 0.267 4.2200 | location (x/L) and velocity (ft/s) |
| 0.500 1.4900 | location (x/L) and velocity (ft/s) |
| 0.973 1.0100 | location (x/L) and velocity (ft/s) |
| 1.000 1.0000 | location (x/L) and velocity (ft/s) |

*** BLOCK 4. s-n and scf data ***

```
1                                   No. of S-N curves defined
1       1                           S-N curve I.D., No. of S-N curve segments (API-X')
0.0000                              cut-off stress range (ksi)
0.4010E+01  0.1000E+09              stress range (ksi) cycles to failure
0.4700E+02  0.1000E+05              stress range (ksi) cycles to failure
1.00     0  1.00                    global scf, flag for bs-curv factor, bs-curv loading factor
0                                   no. of local stress concentration positions
*** BLOCK 5. computation/output option ***
1                       calculation option
0.0000    1.0000    0.1000    response location definition
0.0                     gravitational acceleration
0.05      0.3           power cutoff,  primary zone amplitude limit
1.0                     power value exponent (0 - equal probabilities;1 - power ratio)
3.33      0.4           Higher harmonics factor, Higher harmonics threshold
0.5                     Traveling wave excitation ratio
4                       Beta control number
0                       flag for selecting ID/OD for fatigue calculation
84.00                   Reference diameter for A* calculation
0                       flag for importing nodal effective tension and mass, (0=no;1=yes)
0                       flag for MATLAB animation data output, (1=yes;0=no)
0                       flag for generating *.s7log file, (0=no;1=yes)
0                       flag for generating *.s7dmg file, (0=no;1=yes)
0                       flag for generating *.s7fat file, (0=no;1=yes)
0                       *.s7out file selection, (0=*.s7out, 1=*.s7out1, 2=*.s7out1+*.s7out2)
0                       flag for calculating fatigue with zero-crossing method (1=yes;0=no)
0                       flag for calculating first mode in-line fatigue damage (1=yes;0=no)
0                       flag for generating *.s7str file, (1=yes;0=no)
1                       flag for non-orthogonal damping (1=y;0=n)
```

```
    0                   flag for lift table (0 = common.CL)
    0                   flag for stick-slip hysteresis (0=no;1=yes) [tolerance of convergence if yes]
0                   flag for generating *.s7curv file, (0=no;1=yes)
0                   flag for generating *.s7zeta-hyst file, (0=no;1=yes)
*** BLOCK 6. supplemental data ***
    0.10000E+07             rot stiffness at x=L:lbf-ft/rad
    0.10000E+07             rot stiffness at x=0:lbf-ft/rad.

if nmodel =  6 (pinned-pinned tensioned beam w/two rot springs)
provide rotational stiffness at each end
if nmodel =  9 (free-pinned (w/spring) beam w/varying tension  origin at free end)
provide translational stiffness at x = L
if nmodel = 19 (free-pinned (w/spring) beam w/o tension  origin at free end)
provide translational stiffness at x = L
if nmodel = 33 (inclined cable)
provide chord inclination (angle)
*** BLOCK 7. time history data ***
1           flag for stress time history
NODES=1,25,50,75,100    Output node ranges
```

# APPENDIX E VIV TECHNICAL REFERENCES

## E.1 VIV TECHNICAL REFERENCES

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# APPENDIX F EXCERPT OF VERSION 4.8 AXIAL FLOW DAMPING TERMS

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Issued as Revision 0, 23 November 2026
Doc Ref: Atlas:\...\t2023.j507.005.0_user_guide_v5.0.odt
amogconsulting.com
EIN 20-4906471
TX PE Firm F-11821

## F.1 EXCERPT OF VERSION 4.8 AXIAL FLOW DAMPING TERMS

For Jumper VIV, the hydrodynamic damping model needed to be modified to accommodate axial flow. Under pure axial flow a jumper consists of power-in regions that are perpendicular to the flow and damping regions that are parallel to the flow as presented in Figure F-1. In a typical flow the total damping, $\zeta_n$, of any node *n*, is the summation of the structural and hydrodynamic damping as per Equation 6 and 7.

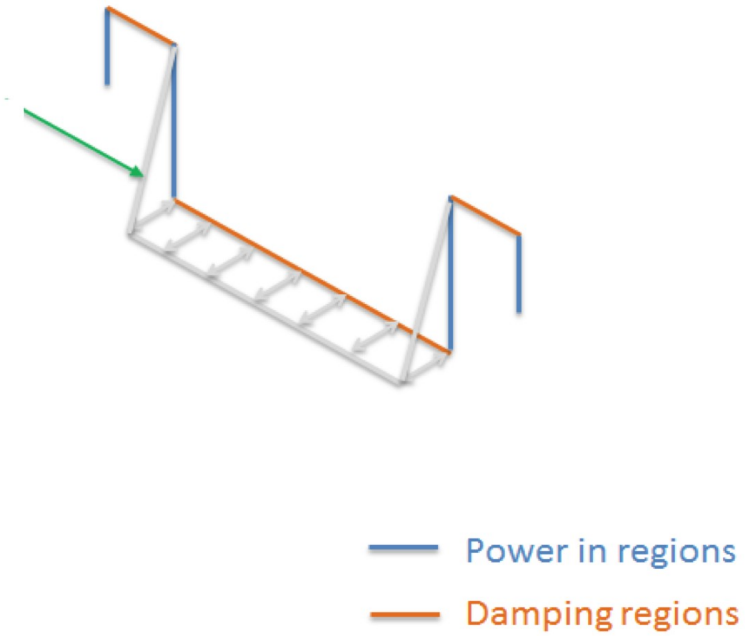


Figure F-1: Jumper schematic highlighting power-in and damping regions when modeling axial flow

$$\zeta_n = \zeta_{structural} + \zeta_{hydro} \qquad \text{Equation 6}$$

$$\zeta_n = \zeta_{structural} + \frac{\int r_h(z) Y_n^2(z)\, dz}{2\omega_n M_n} \qquad \text{Equation 7}$$

The previous SHEAR7 hydrodynamic damping model had three hydrodynamic damping coefficients as per Equation 8 and 9.

$$If \quad Vr<7, \quad then \quad r_h(z) = \frac{\omega \pi \rho D^2}{2}\left[\frac{2\sqrt{2}}{\sqrt{\mathrm{Re}_\omega}} + C_{CD1}\left(\frac{A}{D}\right)^2\right] + C_{D2}\rho DV \qquad \text{Equation 8}$$

$$If \quad Vr>7, \quad then \quad r_h(z) = C_{D3}\rho\frac{V^2}{\omega} \qquad \text{Equation 9}$$

The new damping model included in SHEAR7 version 4.8 has two additional damping coefficients to "turn off" the still water damping and add in axial flow damping as per Equation 10 and 11.

$$If \quad Vr<7, \quad then \quad r_h(z)=\frac{\omega \pi \rho D^2}{2}\left[C_{D0}\frac{2\sqrt{2}}{\sqrt{\mathrm{Re}_\omega}}+C_{D1}\left(\frac{A}{D}\right)^2\right] + C_{D2}\rho DV + C_{D4}\rho DV^2 \qquad \text{Equation 10}$$

$$If \quad Vr>7, \quad then \quad r_h(z)=C_{D3}\rho\frac{V^2}{\omega}+C_{D4}\rho DV^2 \qquad \text{Equation 11}$$

### F.1.1 Version 4.7 damping coefficient input parameters

The input .dat file had the following data for each structural zone.

| | |
|---|---|
| 0.0 1.0 | Zone start and end point in x/L |
| 0.027 0.027 0.021 | Hydro strength inside diameter (in) |
| 1.65405E-08 0.933 0.0 | Inertia ($m^4$) mass (kg/m) sbmg wt (kt/m) |
| 3.62E+10 1 | Modulus of Elasticity (N/m**2), S-N Curve I.D. No. |
| 0.4 0.18 1.00 1 | Bandwidth, St code, Cl reduction factor, zoneCLtype |
| 1.00 0.20 0.18 0.20 | $C_A$, $C_{D1}$, $C_{D2}$, $C_{D3}$, (For bare risers, 1.0 02, 0.18, 0.2) |

### F.1.2 Version 4.8 damping coefficient input parameters

For use with conventional riser models, the input data would be as follows:

| | |
|---|---|
| 0.0 1.0 | Zone start and end point in x/L |
| 0.027 0.027 0.021 | Hydro strength inside diameter (in) |
| 1.65405E-08 0.933 0.0 | Inertia ($m^4$) mass (kg/m) sbmg wt (kt/m) |
| 3.62E+10 1 | Modulus of Elasticity (N/m**2), S-N Curve I.D. No. |
| 0.4 0.18 1.00 1 | Bandwidth, St code, Cl reduction factor, zoneCLtype |
| 1.00 1.0 0.2 0.18 0.2 0 | $C_A$, $C_{D0}$, $C_{D1}$, $C_{D2}$, $C_{D3}$, $C_{D4}$ |

To model axial flow damping in a specific zone, the input data would be as follows:

| | |
|---|---|
| 0.0 1.0 | Zone start and end point in x/L |
| 0.027 0.027 0.021 | Hydro strength inside diameter (in) |
| 1.65405E-08 0.933 0.0 | Inertia ($m^4$) mass (kg/m) sbmg wt (kt/m) |
| 3.62E+10 1 | Modulus of Elasticity (N/m**2), S-N Curve I.D. No. |
| 0.4 0.18 1.00 1 | Bandwidth, St code, Cl reduction factor, zoneCLtype |
| 1.00 0.0 0.0 0.0 0.0 .nn | $C_A$, $C_{D0}$, $C_{D1}$, $C_{D2}$, $C_{D3}$, $C_{D4}$ |

### F.1.3 Developing a SHEAR7 recommended practice in modeling jumpers

- NOT YET BENCHMARKED FOR JUMPER PREDICTION
- Specify input flow velocity to map onto a straight line equivalent to the jumper.
- Assign each straight pipe segment of the jumper to be a different zone.
- Determine the type of damping appropriate to each zone and specify the 5 input coefficients, zone by zone.
- Pay attention to new research and model tests to obtain latest on calibration and lessons learned.
- **It is noted that the axial flow damping capability available from SHEAR7 version 4.8 remains as an experimental feature and is yet to be fully verified. Further testing has been planned for calibration against other model tests and field data. Although Axial Damping Coefficients are available from regulations associated with offshore analysis, these have not been verified for VIV predictions in SHEAR7. It is recommended that users set this parameter to 0.0 for their analyses.**

# APPENDIX G IN-LINE VIV MODELING USING SHEAR7

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## G.1 IN-LINE MODELING USING SHEAR7

The selection of the correct parameters can enable SHEAR7 to model the effects of freespan in-line VIV. Rigid cylinder forced model testing data published in Ref [1] has enabled a conservative set of lift coefficient curves to be created. Flexible beam response from Ref [2] has been used to make comparisons to.

### G.1.1 Lift Curves

Figure G-1 shows a summary of the latest data of A/D limits where the value of CL = 0, plotted on top are the *common.s7cl Table 7* in-line CL curves implemented in a lift coefficient table of SHEAR7. Note that to obtain a conservative estimate of the response (*A/D*), one must set the choice of A/D values high.

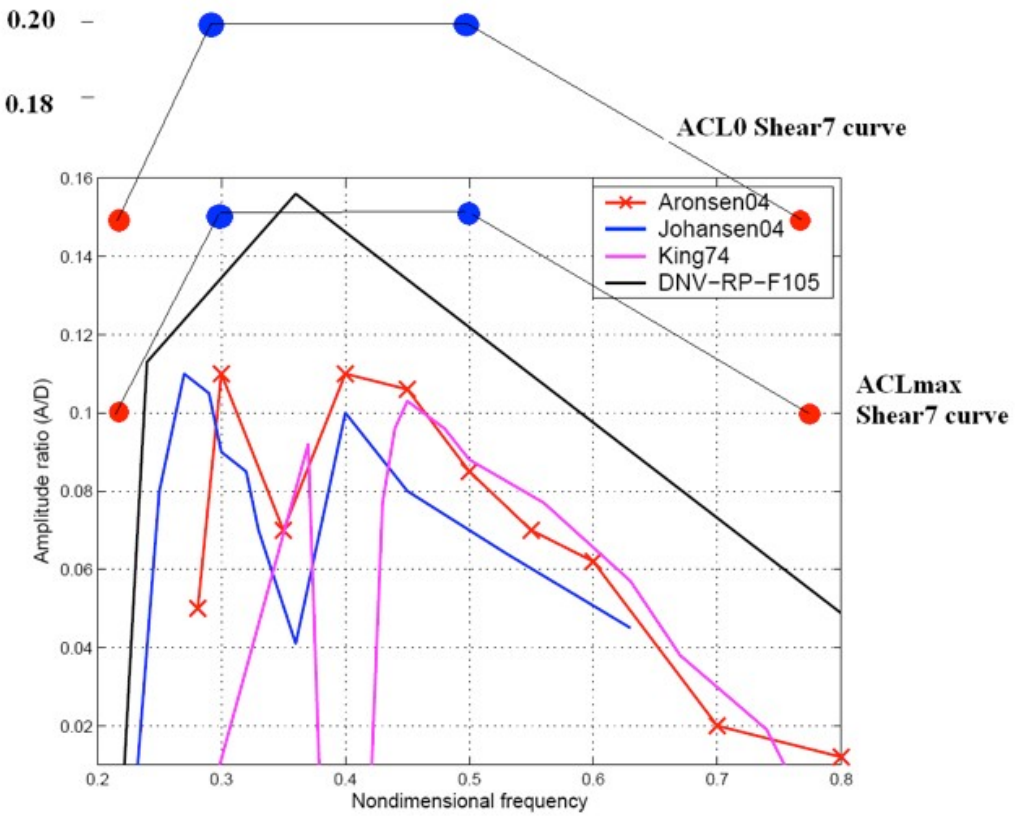


Figure G-1: Summary of A/D at CL = 0 limits from Ref [1], along with limits of common.s7cl curves for *common.s7cl Table 7*

The lift coefficient values take the form of two different curves shown in Figure G-2. Choices of the values of CL come from a conservative estimate of those found from the model test experiments where the highest CL value measured was 0.1.

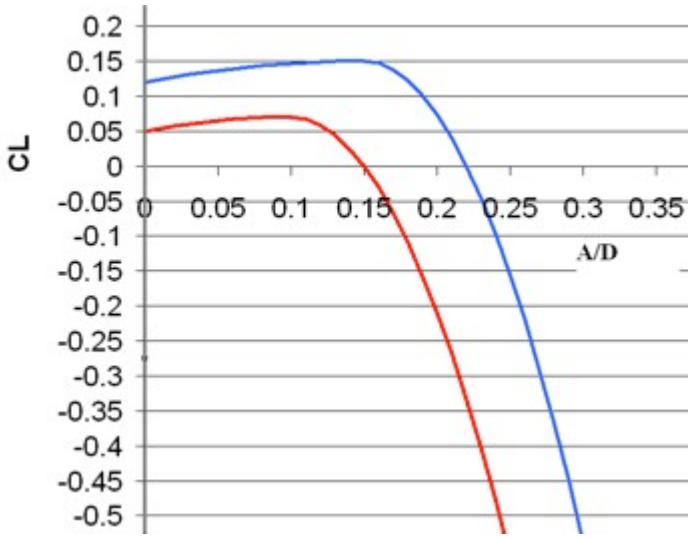


Figure G-2: *common.s7cl curves for common.s7cl Table 7*

As shown in Figure G-2 these curves are applied at four (4) different values of Normalized frequency. Similarly, for a vibrating structure, normalized frequency can be described in terms of reduced velocity or by the parameter *Fn/Fvo*. The values of all these parameters for the application of the new curves is shown in Table G1.

Table G1: Application Of Curve At Various Values Of VIV Frequencies

| Curve | Vr | Norm. Freq. | Fn/Fvo |
|---|---|---|---|
| 1 | 1.28 | 0.78 | 2.36 |
| 2 | 2 | 0.5 | 1.52 |
| 2 | 3.33 | 0.3 | 0.91 |
| 1 | 4.76 | 0.21 | 0.64 |

## G.1.2 Reduced Velocity Bandwidth and Strouhal Number

In order to have the appropriate bandwidth and center of excitation of SHEAR7 to model freespan in-line VIV the St Number and the Bandwidth value have to be modified. The values appropriate for this are shown in Table G2, along with the corresponding ranges of excitation.

Table G2: Choices Of St Number, Bandwidth And Resulting Excitation Ranges

| | | | Vr Excitation Range | | Norm. Freq. Range | | Fn/Fvo Range | |
|---|---|---|---|---|---|---|---|---|
| Case | St Number | Bandwidth | Lwr | Upr | Lwr | Upr | Lwr | Upr |
| Standard Cross Flow | 0.18 | 0.4 | 4.4 | 6.7 | 0.15 | 0.23 | 0.83 | 1.25 |
| Conservative In-line | 0.33 | 1.15 | 1.29 | 4.77 | 0.21 | 0.78 | 0.63 | 2.35 |

**common.s7cl Table**

The common.s7cl entries relating to inline VIV are shown below:

*** CLtype 7 = Very Conservative In-line excitation model

4 nndfreq(1): number of non-dimensional frequencies

0.64 0.15 0.1 0.07 0.05 -1 ndfreq(), aCL0, aCLmax, CLmax, CLa0,

0.91 0.2 0.15 0.15 0.12 -1

1.52 0.2 0.15 0.15 0.12 -1

2.36 0.15 0.1 0.07 0.05 -1

*** CLtype 8 = In-line excitation model

4 nndfreq(1): number of non-dimensional frequencies

0.64 0.125 0.075 0.07 0.05 -1 ndfreq(), aCL0, aCLmax, CLmax, CLa0,

0.91 0.175 0.125 0.15 0.12 -1

1.52 0.175 0.125 0.15 0.12 -1

2.36 0.125 0.075 0.07 0.05 -1

**Summary of changes**

1. St Number → 0.33
2. Bandwidth → 1.15
3. Zone CItype → change to reference the correct table number in common.s7cl

4. common.s7cl file → Add the new common.s7cl table to the common.s7cl file.

**Additional notes**

Note: Sensitivity to added mass is important to consider when doing inline VIV prediction. The added mass will reduce through the inline lock-in region resulting in a slightly higher natural frequency. Sensitivity could involve running the analysis with Ca=0.5 to produce the modes. The lift curves have been intentionally made conservative in their amplitude of response so that curvatures which are raised to a power when computing fatigue compensate for a changing frequency of vibration on the fatigue damage predictions. An example is that a 30% over-prediction of curvature, raised to a power of 3, will lead to a 2.2 times larger fatigue damage rate.

### G.1.3 Example in-line verification

A verification procedure was conducted to benchmark SHEAR7 version 4.7 in-line calculations against an experiment recorded by Passano, Larsen et. al [2].

OMAE2010-20330 was a paper produced to summarize and explain a series of flexible riser experiments including pure in-line VIV response. The data was taken from a VIV Model Test program of a free span using a long elastic pipe model.

For the example, the third and final experimental test series, Test series 75 has been used which produces the greatest range of response for Mode 1 in-line.

The peak A/D response along the span length is shown for predictions and experiments in Figure G-3 *common.s7cl Table 7* is the dashed line, *common.s7cl Table 8* the solid line and experiments are marked with crosses.

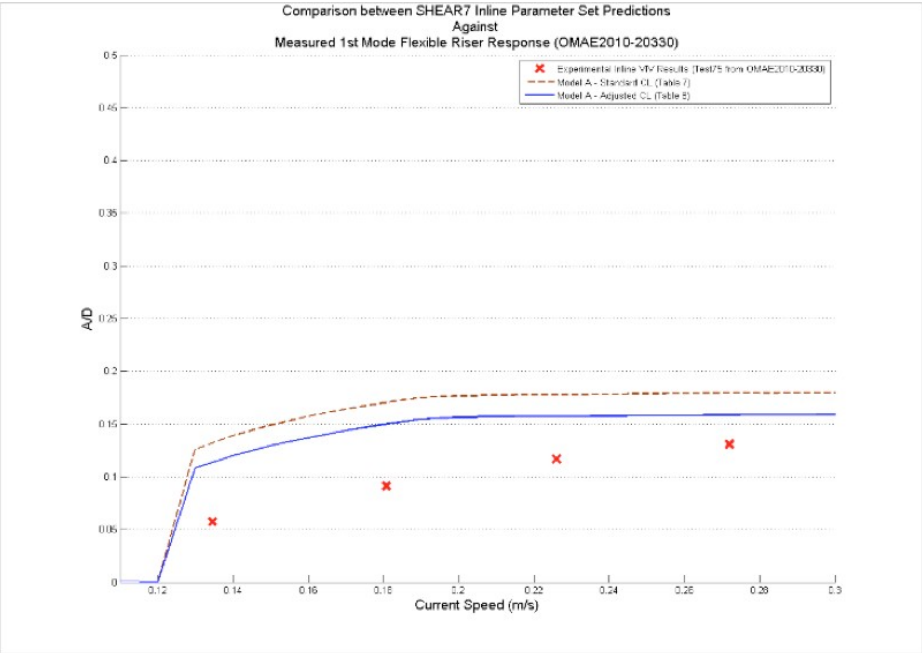


Figure G-3: *Comparison between SHEAR7 using common.s7cl Tables 7 & 8 and the Test 75 Series Experimental Results A/D vs Current Velocity*

In using SHEAR7, the parameter sets shown in the below were used to achieve the results stated.

Table G3: SHEAR7 In-line Parameters

| Parameter | Inline |
|---|---|
| Bandwidth | 1.15 |
| Strouhal No. | 0.33 |
| Lift Reduction Factor | 1 |
| Zone CL type | 7 |
| Power Ratio Cutoff Level | 0.05 |
| Primary Zone Amplitude Limit | 0.3 |
| Power Ratio Exponent | 1 |

**References**

[1] OMAE2005-67393 [Aronsen, et. al. “Hydrodynamic Coefficients from in-line VIV experiments”]; as well as Aronsen PhD thesis.

[2] Passano E, Larsen C.M. et al (2010). “OMAE2010-20330 VIV of Free Spanning Pipelines: Comparison of Response from Semi-Empirical Code to Model Tests”. Marintek & Dep. Of Marine Technology, NTNU Norway.

# APPENDIX H UNDERSTANDING $A^*$, $c^*$ AND $U_f$

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## H.1 UNDERSTANDING $A^*$, $c^*$ AND $U_f$

$A^*$, $c^*$ and $U_f$ are new parameters added in SHEAR7 version 4.9. For the first time it is now possible to plot a measure of response amplitude versus a damping parameter, collapsing thousands of runs on a single plot. It is possible to do parameter studies and quickly compare the effect of, for example, changing the fraction of strake coverage.

$A^*$ is defined as:

$$A^* = \frac{A_{rms}}{D_{ref}} = \frac{1}{D_{ref}} \sqrt{\frac{1}{L_{in}} \int_{L_{in}} y_{rms}^2(x)\, dx} \qquad \text{Equation 12}$$

$A^*$ is the spatial RMS value of the temporal RMS response amplitudes in the power-in region, normalized by the reference diameter that is specified by the user in the *.s7*dat file. $A^*$ includes the contributions from the resonant and non-resonant modes.

$U_f$ is defined as the RMS current velocity in the power-in region, as per Equation 13.

$$U_f = \sqrt{\frac{1}{L_{in}} \int_{L_{in}} U^2(x)\, dx} \qquad \text{Equation 13}$$

The parameter $c^*$ is a dimensionless damping parameter which is based on the equilibrium between power into the system from lift forces to the power out of the system due to damping. In general as damping is increased the response amplitude will fall. Also, it is generally true that even if the damping is constant, the response will increase with current speed. $c^*$ is a damping parameter that includes the effects of both damping coefficient as well as current speed on the response.

The definition of $c^*$ is defined in Equation 14, where $c_{equiv}$ is the total equivalent damping constant for the system. $c_{equiv}$ is defined in Equation 15.

$$c^* = \frac{c_{equiv}\, \omega}{\frac{1}{2} \rho U_f^2} \qquad \text{Equation 14}$$

$$c_{equiv} = \frac{\Pi_{in}}{L_{in} A_f^2 \omega^2} \qquad \text{Equation 15}$$

$c_{equiv}$ makes use of the fact that at steady state $\Pi_{in} = \Pi_{out}$ . In words, $c_{equiv}$ is the equivalent damping per unit length that if it were applied over a length of cylinder equal to the length of the power-in region, it would dissipate the same amount of power as the actual damping distributed over the entire riser.

## H.2 USE OF $A^*$ AND $c^*$

Figure H-1 below shows a plot of $A^*$ versus $c^*$ for dozens of different risers modeled in SHEAR7 using lift coefficient Table 1. The scenarios shown are models of shallow, medium and very deep water top tension risers, SCRs and lazy wave risers, with varying amounts of strake coverage in uniform and sheared flows. All of the points fall on one rather smooth curve. This is a consequence of using lift coefficient Table 1, in which the lift coefficient is a function only of A/D and not reduced velocity.

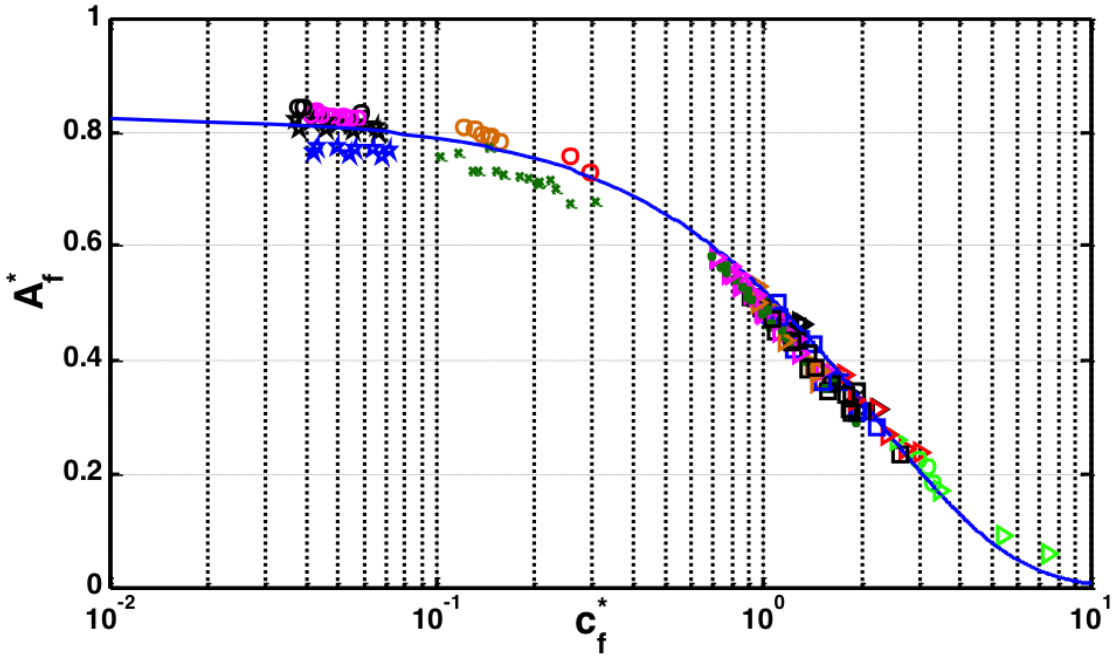


Figure H-1: $A^*$ versus $c^*$ for a wide range of top tension, SCR and lazy wave risers with and without strakes.

A plot such as this allows a direct comparison of cases with widely varying input parameters. Another use of these plots is to detect problems in program execution or theory. Figure H-2 shows the same cases run with a development version of SHEAR7 while testing out the recent improvement to the program, known as the beta correction. In this figure there is an odd looking branch of data points that curve upward from the main body of data points; upon closer inspection revealed that the lift coefficient iteration that is part of the beta correction was not converging correctly. It was this plot that drew our attention to it, allowing us to fix the bug quickly. It is recommended when running a large number of cases, one should get in the habit of seeing how the data looks in such a plot.

It should be noted that when using lift coefficient Table 2, an $A^*$ versus $c^*$ plot will not reveal a smooth curve. Rather there will be considerable scatter, because the lift coefficient varies with A/D as well as reduced velocity.

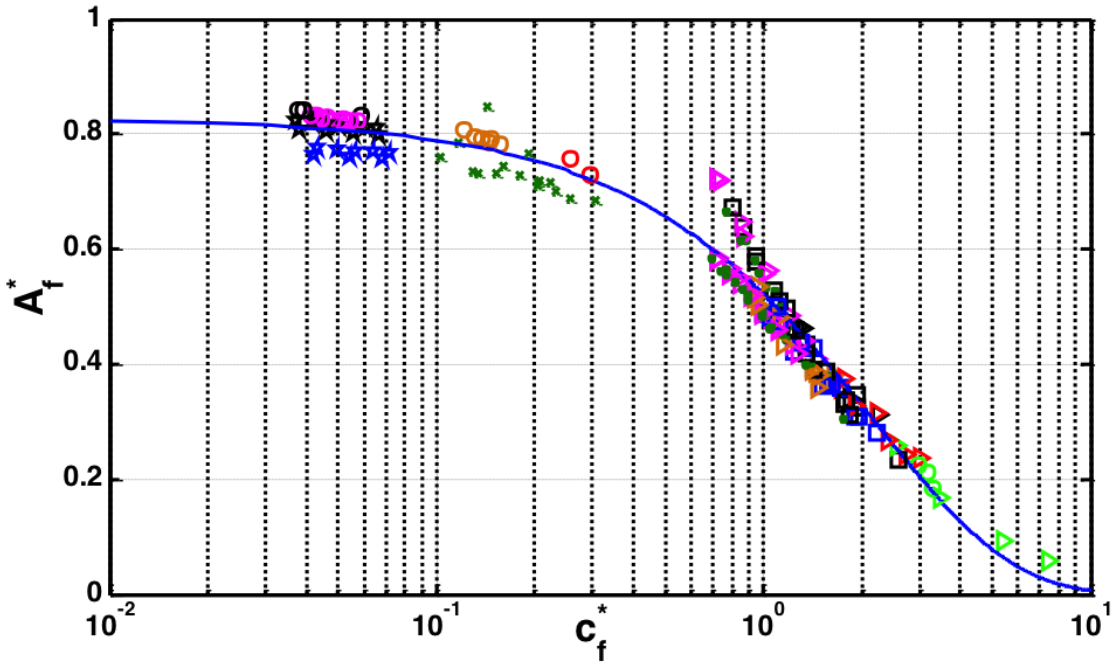


Figure H-2: $A^*$ versus $c^*$ for a wide range of top tension, SCR and lazy wave risers with and without strakes. The branch on the top side of the curve revealed a program bug during development testing that was subsequently resolved prior to release.

# APPENDIX I VARYING STRUCTURAL DAMPING "STICK-SLIP" BETA TEST MODULE

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## I.1 VARYING STRUCTURAL DAMPING “STICK-SLIP”

SHEAR7 v4.11 added a beta test version of a varying structural damping “stick-slip” module, appropriate for modeling long flexible ocean structures with helically wound layers such as:

- Umbilicals,
- Power cables and
- Unbonded flexible risers.

The implementation of this module is based on references [1] through [6] shown in Section I.8, along with some additional improvements.

This is a BETA release for the varying structural damping module. This has not been extensively benchmarked and should be considered for research purposes only. As this is a beta test module, we value any feedback on features and experiences.

### I.1.1 Stress & Fatigue

This module is intended to predict the global curvature response of unbonded flexible structures undergoing VIV. Typically it would be expected that stress in any of the components of the multi-layered structure would be a non-linear function of the curvature response amplitude. The current formulation of stress and fatigue within SHEAR7 assumes the structure is a homogeneous pipe. Accordingly stress and fatigue should be estimated via a separate tool or method that can take global curvatures as an input.

### I.1.2 Theory

The detailed theory upon which this module is based is contained in the SHEAR7 theory manual, available to current User Group Members on request.

## I.2 NOMENCLATURE FOR THIS APPENDIX

| | |
|---|---|
| $\zeta_S$ | Structural damping expressed as fraction of viscous critical damping |
| $\zeta_M$ | Material damping expressed as fraction of viscous critical damping |
| $\zeta_{Stick\text{-}slip}$ | Stick-slip damping expressed as fraction of viscous critical damping |
| **f** | Mode shape |
| $\omega_n$ | Natural frequency |
| **A/D** | Non-dimensional amplitude of VIV |
| **BM** | Bending Moment |
| $c_S(z)$ | Sectional viscous equivalent structural damping coefficient / length |
| $c_{s\text{-}s}(z)$ | Stick-Slip sectional viscous equivalent structural damping coefficient / length |
| **M** | Dominant mode |
| **m(z)** | Mass per unit length at location z |
| **p** | Pressure |
| $r_{hydro}(z)$ | Hydrodynamic sectional viscous equivalent structural damping coefficient / length |
| ***R*** | Damping |
| $R_{cr}$ | Critical damping |
| **T** | Tension |
| | |
| $U_b$ | Bending potential energy per cycle |
| $U_T$ | Geometric potential energy due to tension per cycle |
| $W_h$ | Dissipated energy per cycle |
| $w_{n,h}$, $u_{n,b}$, $u_{n,T}$ | Sectional energy properties per unit length for mode n at location z |
| **y”** | Curvature |
| ***z*** | Axial location along umbilical/riser |

## I.3 MODULE FUNCTION

The intent of having a new procedure for VIV analysis is to incorporate the effects of energy loss during slippage between layers of unbonded flexible structures during VIV response. This behavior can be quantitatively input through a stick-slip hysteresis curve as part of the VIV analysis which in turn can result in higher levels of structural damping in unbonded umbilical structures and flexible risers. The new procedure follows the flow chart in Figure I-1.

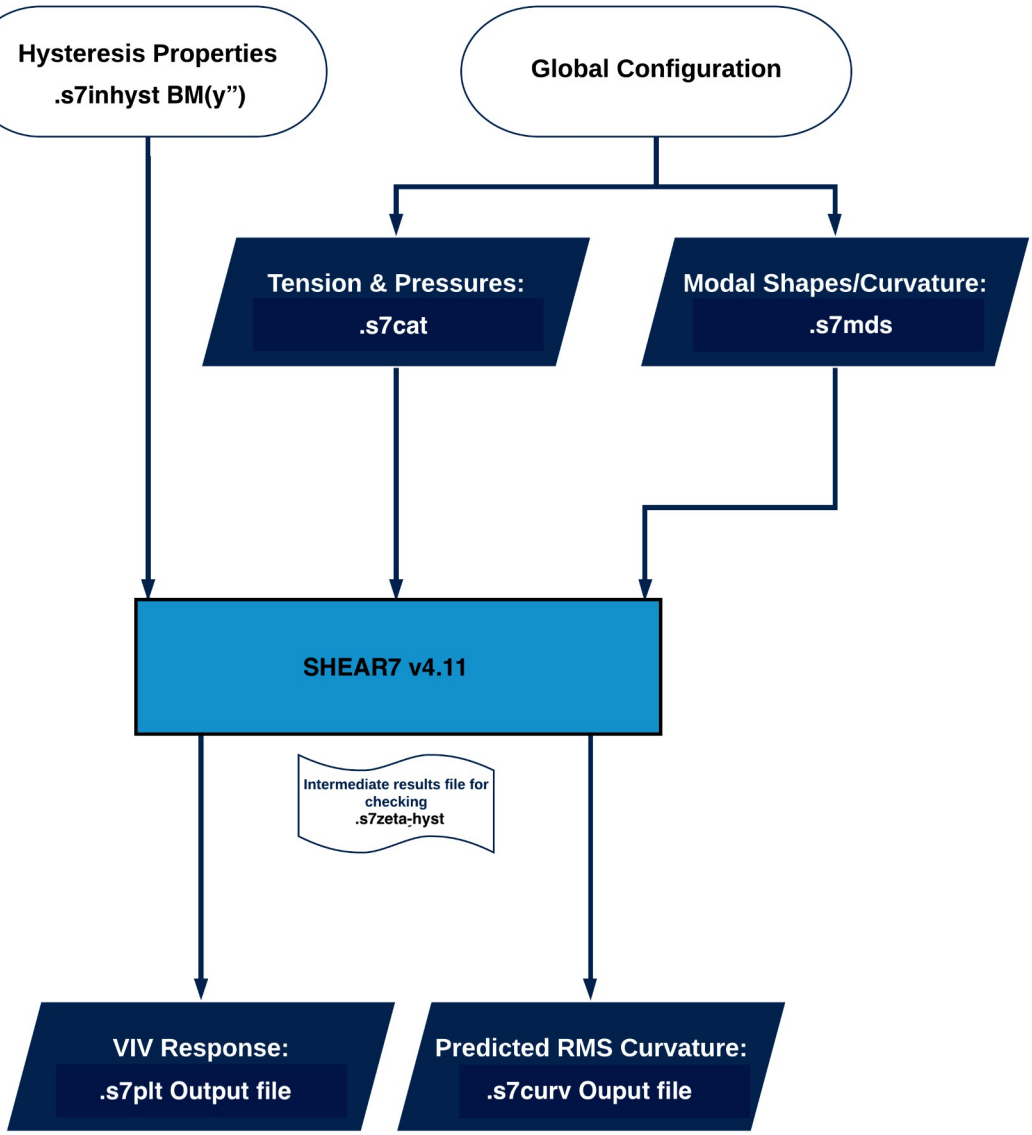


Figure I-1: Inputs/Outputs Summary for Varying Structural Damping Module

## I.4 REQUIRED SETUP

To run the varying structural damping module the following SHEAR7 input files (*.s7mds and *.s7cl) along with the new/updated SHEAR7 input files are required, as listed below:

*.s7mds
- Input file containing modal frequency information is always required (7.3)
- For SHEAR7 v4.11 and beyond the **modal slope column must be populated**. Previous versions also required this column however some users chose not to use it.

*.s7cl
- Input file containing lift tables is always required.

*.s7dat
- v4.11 and beyond require three new lines in BLOCK 5 (See Figure I-2).
  - One line to toggle stick-slip damping.
  - Two lines to toggle the new output files.

*.s7cat
- The *.s7cat file has a similar format as previous versions of SHEAR7, with the addition of a new column which is the static mean curvature (See Figure I-4).
- A *.s7cat file must be used when running stick-slip damping and the static mean curvature column must be present.

*.s7inhyst
- NEW INPUT FILE to specify the hysteresis behaviour.
- Defined as per Figure I-5. The tension, pressure, stick slope, slip slope and slip curvature are all on one line.

### I.4.1 Relevant changes to .s7dat file

Relevant input lines to the .s7dat file are shown below in Figure I-2 for this module.

```
*** BLOCK 5. computation/output options ***
3 slope_added_1000  Calculation option, Response defined by uniquely named .s7mds file
      0.0000       1.0000     0.1000        response location definition
      0.0                                   gravitational acceleration
      1.0         0.65                      power cutoff, primary zone amplitude limit
      1.0                                   power value exponent (0 - equal probabilities;1 - power ratio)
       3.33   3                         high harmonics factor, high harmonics threshold
       0.5                                 traveling wave excitation ratio
       4                                   beta control number (0=no beta iterations,n=n beta iterations, up to n=10)
       0                                   Riser ID/OD for calculating stress (0=OD,1=ID)
      2.1336000                            reference diameter for Af* and cf* calculation
      2   OMAE2016-54816-exmpl-Umb1  flag for importing nodal effective tension and mass, (0=no;1=yes)
      0                                       flag for MATLAB animation data output, (0=no;1=yes)
      1                                       flag for generating *.s7scr file, (0=no;1=yes)
      0                                       flag for generating *.s7dmg file, (0=no;1=yes)
      1                                       flag for generating *.s7fat file, (0=no;1=yes)
      1                                       *.out file selection, (0=*.out, 1=*.out1, 2=*.out1+*.out2)
       0                                  flag for calculating fatigue with zero-crossing method (1=yes;0=no)
       0                                  flag for calculating first mode in-line fatigue damage (1=yes;0=no)
       0                                  flag for generating *.s7str file, (1=yes;0=no)
       0                                  flag for non-orthogonal damping  (1=yes;0=no)
       0                                     lift table file (0 = common cl)
2 0.01  Umb01-N                        flag for stick-slip hysteresis (0=no;1=yes) [tolerance of convergence if yes]
1                                flag for generating *.s7curv file, (0=no;1=yes)
1                                flag for generating *.s7zeta-hyst file, (0=no;1=yes)
```

Figure I-2: Example changes to *.s7dat input file format

```
*** BLOCK 5. computation/output options ***
3 slope_added_1000  Calculation option, Response defined by uniquely named .s7mds file
      0.0000       1.0000     0.1000        response location definition
      0.0                                   gravitational acceleration
      1.0          0.65                     power cutoff, primary zone amplitude limit
      1.0                                   power value exponent (0 - equal probabilities;1 - power ratio)
       3.33   3                       high harmonics factor, high harmonics threshold
       0.5                               traveling wave excitation ratio
       4                                 beta control number (0=no beta iterations,n=n beta iterations, up to n=10)
       0                                 Riser ID/OD for calculating stress (0=OD,1=ID)
      2.1336000                          reference diameter for Af* and cf* calculation
      2   OMAE2016-54816-exmpl-Umb1  flag for importing nodal effective tension and mass, (0=no;1=yes)
      0                                     flag for MATLAB animation data output, (0=no;1=yes)
      1                                     flag for generating *.s7scr file, (0=no;1=yes)
      0                                     flag for generating *.s7dmg file, (0=no;1=yes)
      1                                     flag for generating *.s7fat file, (0=no;1=yes)
      1                                     *.out file selection, (0=*.out, 1=*.out1, 2=*.out1+*.out2)
       0                                 flag for calculating fatigue with zero-crossing method (1=yes;0=no)
       0                                 flag for calculating first mode in-line fatigue damage (1=yes;0=no)
       0                                 flag for generating *.s7str file, (1=yes;0=no)
       0                                 flag for non-orthogonal damping  (1=yes;0=no)
      0                                     lift table file (0 = common.cl)
2 0.01  Umb01-N                       flag for stick-slip hysteresis (0=no;1=yes) [tolerance of convergence if yes]
1                                  flag for generating *.s7curv file, (0=no;1=yes)
1                                  flag for generating *.s7zeta-hyst file, (0=no;1=yes)
```

Figure I-3: Example changes to *.s7dat input file format

### I.4.2 Import Common.s7cat

The line toggling the use of the common.s7cat file has been modified to allow the .s7dat file to specify a uniquely named file. This line now has three possible values which are as follows:

- Option 0 – Structural properties are all contained within the .s7dat file.
- Option 1 – Uses an externally prepared structural properties file in a file called common.s7cat.
- Option 2 – Uses an externally prepared structural properties file in a file called rootname.s7cat.

### I.4.3 Stick-Slip Hysteresis Flag

Flag to account for damping from stick-slip hysteresis when calculating the VIV response. Three possible values can be entered in this line as follows:

- Option 0 – SHEAR7 **will not** model stick-slip hysteresis.
- Option 1 – SHEAR7 **will** model stick-slip hysteresis and the hysteresis curves are specified in a file called **rootname.s7inhyst**, where *rootname* is the name of the .s7dat file.
- Option 2 – SHEAR7 **will** model stick-slip hysteresis and the hysteresis curves are specified in a user defined .s7inhyst file.

If stick-slip hysteresis is modeled, the user must also specify a tolerance of convergence. The iteration convergence tolerance is calculated as the percentage change of the stick-slip damping coefficient. This value must be provided after the stick-slip hysteresis flag. Stick-slip hysteresis flag

options are defined in Table I-1.

Table I-1: Stick-Slip Hysteresis Flag Examples

| | | | | |
|---|---|---|---|---|
| OPTION 0: | 0 | | | flag for stick-slip hysteresis |
| OPTION 1: | 1 | 0.001 | | flag for stick-slip hysteresis, tolerance of convergence |
| OPTION 2: | 2 | 0.001 | myhyst | flag for stick-slip hysteresis, tolerance of convergence |

### I.4.4 s7curv output file

The .s7curv file generated by SHEAR7 reports the peak curvature of each resonant mode for each node. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 will not report the .s7curv file
- 1 – SHEAR7 will report the .s7curv file

### I.4.5 s7zeta-hyst output file

The .s7zeta-hyst file generated by SHEAR7 reports the stick-slip damping ratio for a range of tensions and curvatures. Two possible values can be entered in this line as follows:

- 0 – SHEAR7 will not report the .s7zeta-hyst file
- 1 – SHEAR7 will report the .s7zeta-hyst file

## I.5 COMMON.S7CAT INPUT FILE UPDATE

The format of the common.s7cat file remains largely the same as previously defined in the SHEAR7 v4.10 User Guide. However, an additional column of data is required as part of running the varying structural damping module. The column of data represents the mean (static) curvature of the structure to be assessed. An example common.s7cat file showing the added column is provided below in Figure I-4. For SI units, the following are the columns:

- Node number [–]
- Effective tension [N]
- Mass per unit length in air including contents plus added mass [kg/m]
- Mean curvature [rad/m]

| Node # | Tension Variation | Mass per Unit Length | Mean Curvature |
|---|---|---|---|
| 1 | 823.6184682 | 10.07318175 | 0 |
| 2 | 793.7187514 | 0.08757681 | 2.24E-09 |
| 3 | 763.7665645 | 0.08757681 | 0.000600189 |
| 4 | 763.6680475 | 0.08757681 | 0.000376056 |
| 5 | 763.5695211 | 0.08757681 | 0.000227266 |
| 6 | 763.4709909 | 0.08757681 | 0.000128381 |
| 7 | 763.3724591 | 0.08757681 | 6.26E-05 |
| 8 | 763.2739269 | 0.08757681 | 1.88E-05 |
| 9 | 763.1753945 | 0.08757681 | 1.16E-05 |
| 10 | 763.0768621 | 0.08757681 | 3.12E-05 |

Figure I-4: Example changes to the .s7cat input file format

## I.6 S7INHYST INPUT FILE FORMAT

The format of the .s7inhyst file is shown in Figure I-5 and is to be specified as follows:

- Hysteresis curves are to be specified as a bi-linear relationship (stick-slope and a slip-slope);
- Hysteresis curve reference (this line is not read or used by SHEAR7);
- Unit system flag;
- No. of separate curves in file; and
- Tension, Pressure, Stick-slope, Slip-slope, Slip curvature (SI: N, Pa, (N.m)/(rad/m), (N.m)/(rad/m), (rad/m))

Each curve is represented by one line of the file consisting of Stick slope, Slip slope, Slip curvature.

Data can be currently be entered in SI units only.

NOTE: The pressure values are not currently used within the program however are provided for future versions.

```
Umbilical benchmark
0     ! SI Units
2     ! Number of entries
100.0E+03    0   4.422E+06   192E+03   2.74E-04
750.0E+03    0   4.422E+06   215E+03   5.20E-04
```

Figure I-5: Example *.s7inhyst input file format

## I.7 TEST CASE

A test case based on the umbilical described in OMAE2016-54816 [6] has been added to the example files for distribution.

Limited validation has been performed using non-orthogonal damping so it is recommended to always use non-orthogonal damping with the stick-slip option.

Figure I-6 shows the comparison of the curvature response predicted by SHEAR7 with and without stick-slip.

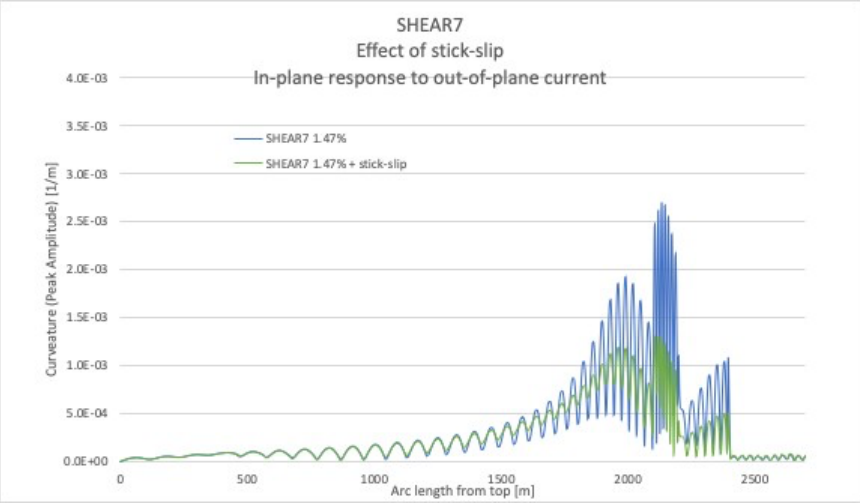


Figure I-6: SHEAR7 predictions on effect of stick-slip on umbilical from OMAE2016-54816

## I.8 REFERENCES FOR VARYING STRUCTURAL DAMPING MODULE

[1] Eassom et al, “Umbilical VIV Fatigue with Mode Number and Mode Amplitude Dependant Structural Damping” (Paper No. 2016-TPC-0877), 2016.

[2] N. Sødahl, O. Steinkjer, E. Gjølmesli, and K. Hansen-Zahl, “Consistent VIV Fatigue Analysis Methodology of Umbilicals,” Vol . 4: Pipeline and Riser Technology, pp. 439–447, ASMEDC, Rotterdam, The Netherlands. 2011.

[3] E. Kausel, ”Advanced Structural Dynamics”. Cambridge University Press. ISBN 978-1-107-17151-0. 2017.

[4] J. K.. Vandiver, “Predicting Lock-in on Drilling Risers in Sheared Flows,” Proceedings of the Flow-Induced Vibration 2000 Conference. Lucerne, Switzerland. (2000, June 18-22).

[5] Z. Tan, P. Quiggin, and T. Sheldrake, “Time Domain Simulation of the 3D Bending Hysteresis Behaviour of an Unbonded Flexible Riser,” OMAE2007-29315. Proceedings of the 26th International Conference on Offshore Mechanics and Arctic Engineering. 2007

[6] E. Passano, S Abtahi and T. Ottesen, “A procedure to include slip damping in a VIV analysis of an umbilical” Proceedings of the ASME 2016 35th International Conference on Ocean, Offshore and Arctic Engineering, OMAE2016. Busan, South Korea, (2016, June 19-24)

# APPENDIX J LONGITUDINALLY GROOVED SUPPRESSION (LGS® ) TECHNOLOGY

# J.1 LONGITUDINALLY GROOVED SUPPRESSION TECHNOLOGY

LGS is a low drag, moderate VIV suppression technology, developed by AMOG, manufactured by Matrix Engineering & Composites for worldwide use.

Default modeling parameters for LGS are provided in Appendix A  Sub-critical Reynolds number characteristics have been provided for 6.2% LGS inline VIV, as typically these applications involve sub-critical Re numbers. 6.2% LGS achieves greater VIV suppression than 3.8% LGS, and is recommended for applications with minimal diameter constraints. For drilling risers that have maximum diameter constraints whilst also maximizing buoyancy, 3.8% LGS is recommended. The value of 3.8/6.2% represents the peak to trough height of the grooves relative to the outermost OD.

LGS has been found to result in a reduced total dynamic VIV drag response as well as have a smaller drag amplification curve as a function of A/D response than circular cylinders.

The following are references on LGS.

## J.1.1 Peer reviewed LGS publications

- OMAE2019-96426. Field trial of vortex-induced vibration suppression technology for drilling riser buoyancy.
- OMAE2018-77716 Mitigation of Pipeline Free Span Fatigue Due To Vortex Induced Vibration using Longitudinally Grooved Suppression.
- OMAE 2017-62219 “Drilling Riser Case Studies Comparing the Drag Performance of LGS Technology to Conventional Buoyancy Units and Fairings.”
- OMAE 2016-54689. “Drag reduction and viv suppression behaviour of LGS technology integral to drilling riser buoyancy units” June 19-24, 2016, Busan, South Korea.

## J.1.2 Independent research on grooved suppression

- OMAE2019-95649. “Staggered Grooves for the Suppression of Vortex-Induced Vibration in Flexible Cylinders”. Yun Zhi Law , Rajeev K. Jaiman. June 9–14, 2019, Glasgow, Scotland, UK
- Wang, J., Chen, F., Shi, C., and Yu, J., 2021, “Mitigation of Vortex-Induced Vibration of Cylinders Using Cactus-Shaped Cross Sections in Subcritical Flow,” JMSE, 9(3), p. 292.

# APPENDIX K OPTIONAL STRESS TIME HISTORY OUTPUT

## K.1 EXAMPLE ILLUSTRATION OF STRESS TIME HISTORY OUTPUT

Figure K-1 shows an illustration of how the optional stress time history is combined when different frequencies are present in the response with their respective time sharing proportions. Half cosine tapers are used to join the different frequencies, as well as the different traveling/standing wave excitation sections. As a default, 10 repeats of the combined signal are generated.

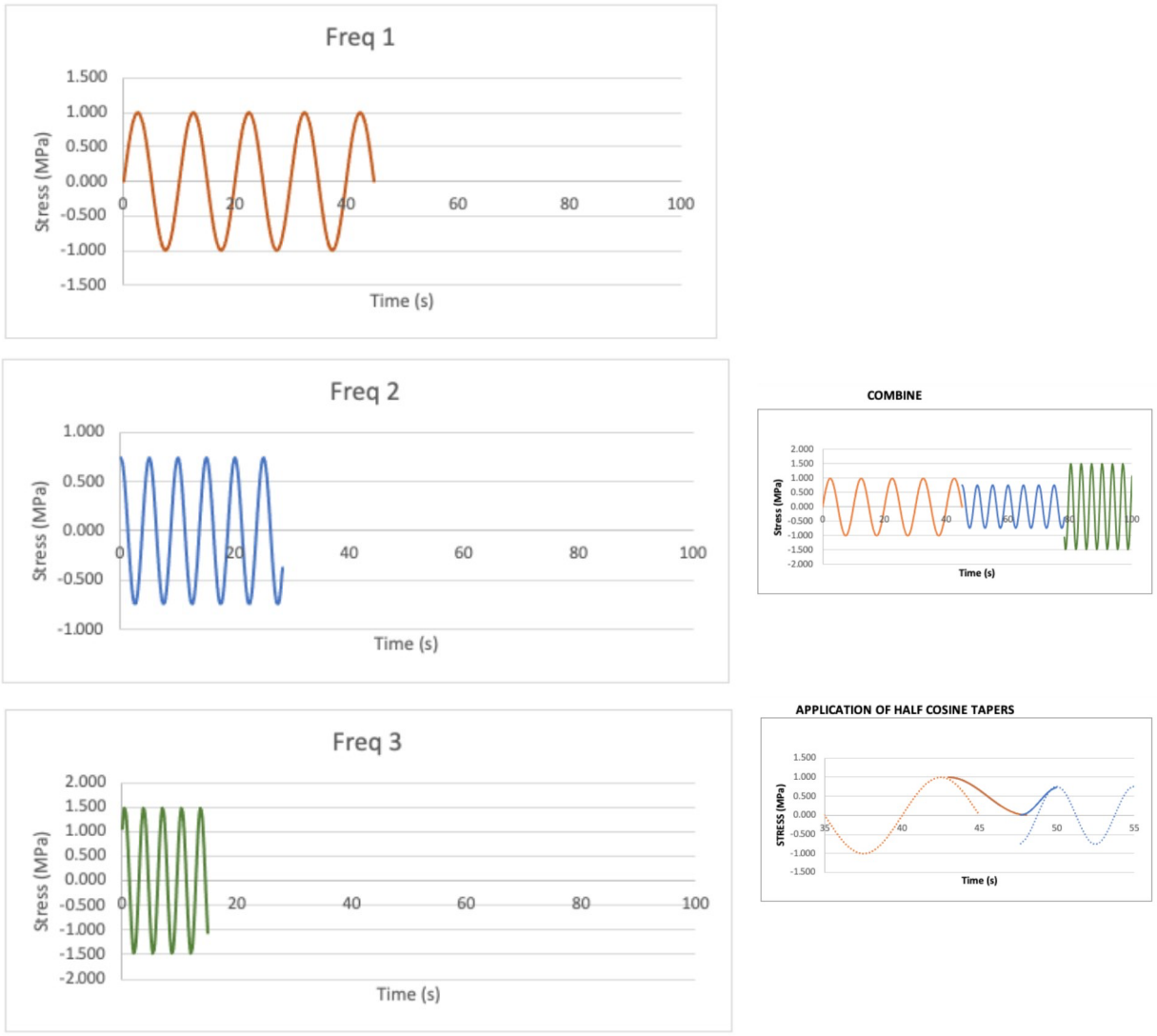


Figure K-1: Illustration of how time sharing is combined for the stress time history

# APPENDIX L TRAVELING WAVE EXCITATION

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EIN 20-4906471
TX PE Firm F-11821

In the context of VIV, standing waves are characterized by a response with stationary modal nodes and antinodes, and no phase propagation along the length of the structure. Figure L-1 demonstrates a uniform current case with purely standing wave excitation, showing clearly defined nodes and antinodes.

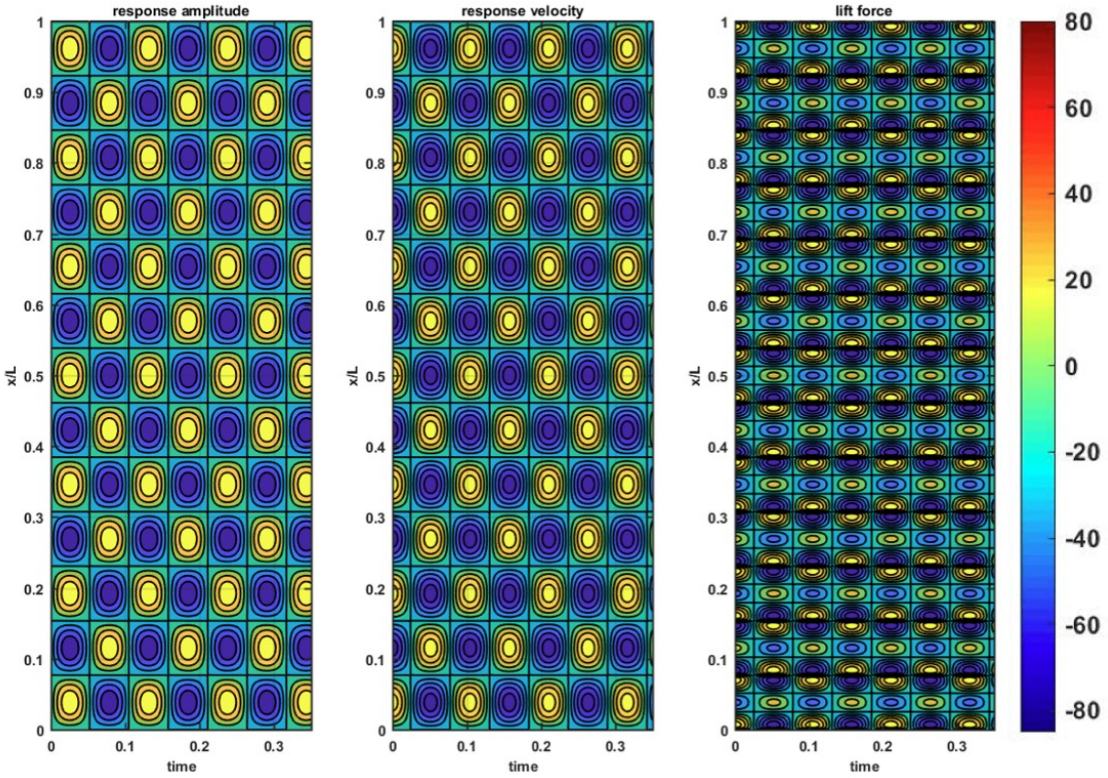


Figure L-1: Uniform current case with only standing wave excitation

In contrast, traveling waves exhibit phase propagation, with the response peak moving along the length of the structure over time. Figure L-2 shows this with the response peaks propagating down along the length of the structure from the power-in region, becoming more representative of a standing wave as it moves away from the power-in region.

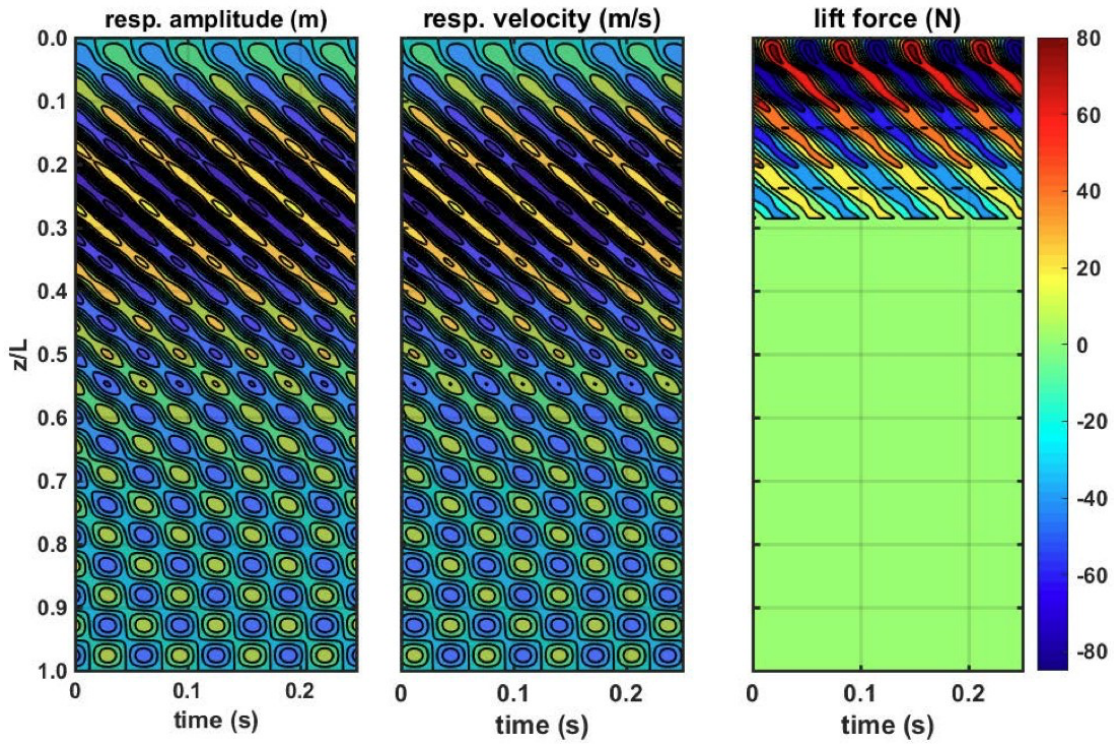


Figure L-2: Bare cylinder in strong shear case with a region of traveling wave excitation

SHEAR7 4.12c and prior versions assume that VIV excitation is entirely standing wave based (i.e. the lift force distribution inside the power in region looks like a standing wave.) This has proven effective for many applications, but field and experimental observations from long flexible structures have shown that real VIV responses often contain significant traveling wave behavior both in the power-out regions as well as inside the power-in regions.

This is particularly true in sheared currents where hydrodynamic damping levels significantly vary along the structure. It appears that having these large power-out regions together with high mode number response results in favorable conditions for the existence of traveling waves inside the power-in region. Most likely because a large amount of the energy is dissipated and only a small amount is reflected at the far boundary, leading to conditions that favor a traveling wave like response (creating a non-reflecting or just partially reflecting boundary condition). A traveling wave excitation model is necessary to properly model the VIV excitation inside the power-in regions. The SHEAR7 v5.0a traveling wave excitation model was developed to better represent this physical reality.

Internally, SHEAR7 calculates separate standing wave excitation and traveling wave excitation responses and combines them according to the specified traveling wave excitation ratio. Each excitation model results in its own VIV response that is reached through a separate set of iterations, ensuring that the traveling wave solution is developed independently rather than being constrained by the standing wave solution. This separation was identified as a key requirement during development and was subsequently implemented in v5.0a. Time-sharing probabilities for the

various excited VIV/modes are currently based on the power ratios computed using the 'standing wave excitation'.

In most cases, the user should:

- **See similar maximum** predicted response (in both amplitude and stress) values between v5.0a and older versions (v4.12c), and;
- note **different distributions** of response amplitude along the structure (i.e. the location along the riser/cable where the maximum occurs may change).

The examples below summarize the behavior commonly seen:

a) Figure L-3, in very uniform current profiles where the response everywhere along the riser will look like a standing wave, the traveling wave excitation distribution will also look like a standing wave (even with the traveling wave excitation ratio set to 1.0) due to it trying to match the standing wave response inside the power-in region. In these situations, the VIV response will be identical to the older 'standing wave excitation' results.

b) Figure L-4, in lightly sheared current profile where the standing wave behavior still dominates the results, the traveling wave excitation will still create a lift distribution that closely resembles a standing wave since that is the shape of the response along the riser/cable. Differences between the standing wave excitation results and the traveling wave excitation results will typically be small.

c) Figure L-5, when the current profiles are highly sheared, then the response is dominated by traveling waves (both inside and outside the power-in region) as a result, enabling the traveling wave excitation will create a lift distribution that matches the traveling wave inside the power-in region and noticeable differences will be observed inside the power-in regions between the results using a traveling or standing wave excitation.

d) Figure L-6, non uniform risers/cables setups (such as partial strake coverage, partial fairing coverage etc) can result in arrangements with very dominant power-out regions. This often leads to infinite or semi-infinite system behavior.

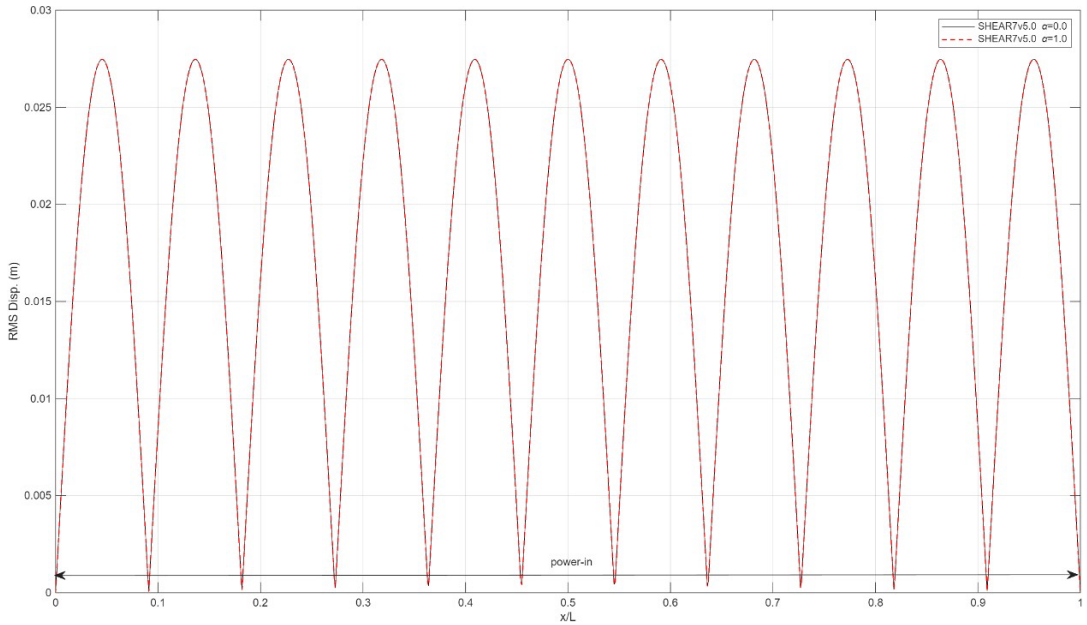


Figure L-3: Example (a), perfectly uniform current profile acting on a bare cylinder: The strong standing wave response that dominates the response (power-in region) means that even with the traveling wave excitation enabled (ratio set to 1.0) the lift distribution will match the standing wave of the response.

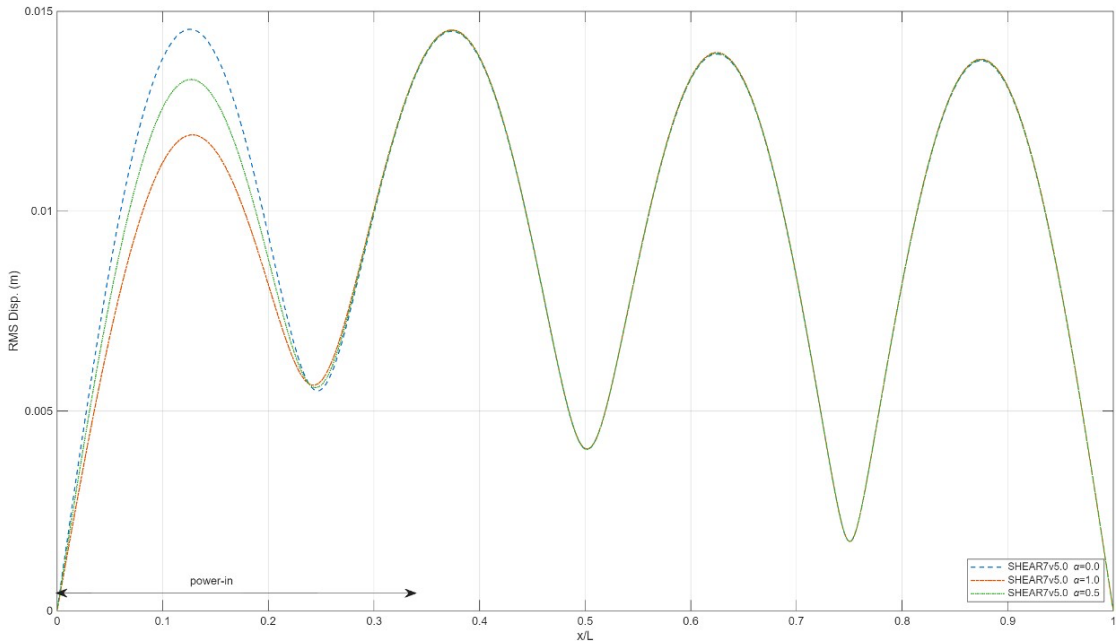


Figure L-4: Example (b), low current and low shear, resulting in a very low mode number response: The traveling wave excitation (α=1.0) results in a response that is very similar to the standing wave excitation results (α=0.0). This happens due to the prominent standing wave response along the riser (and especially inside the power in region)

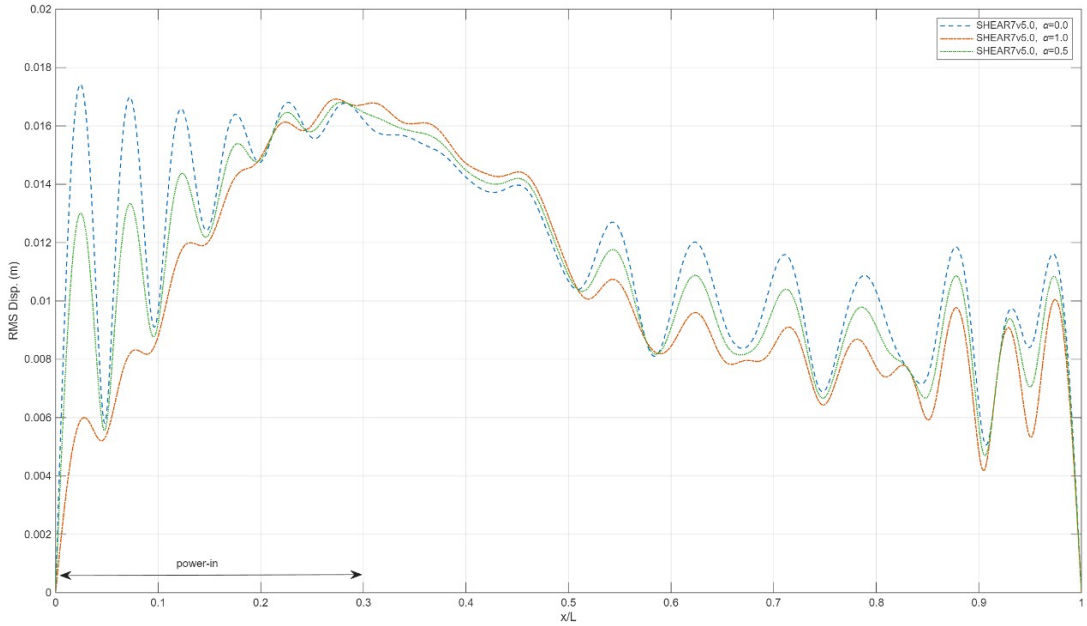


Figure L-5: Example (c), high current and shear, resulting in a high mode number response: The traveling wave excitation (α=1.0) leads to a VIV response that 'grows' as it traverses the power-in region unlike the standing wave excitation result (α=0.0)

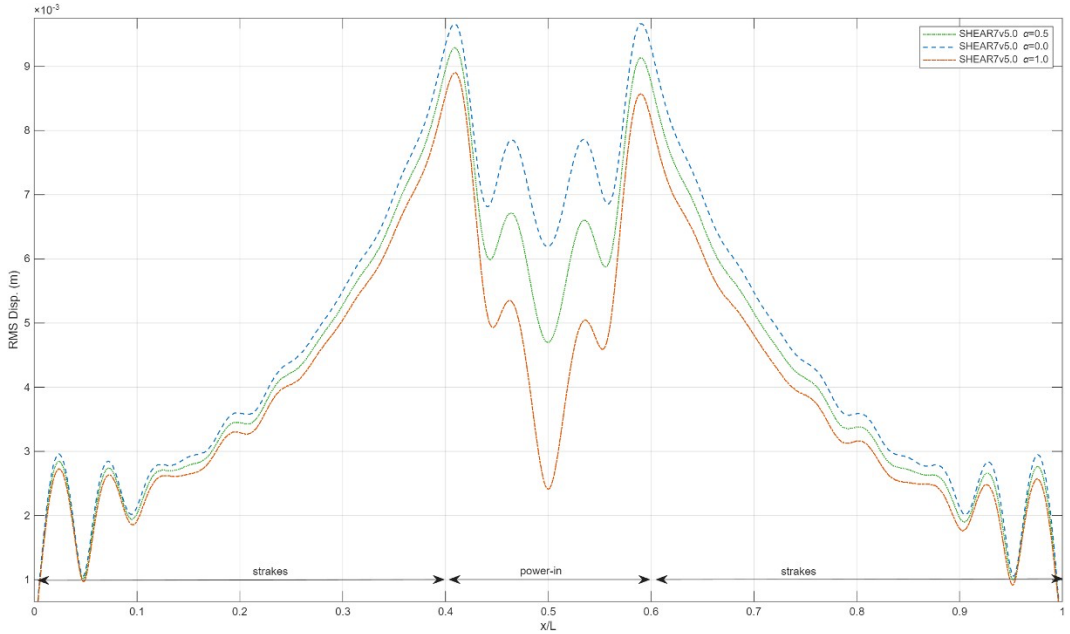


Figure L-6: Example (d), strong uniform current and partial strake coverage: Resulting in a high mode number response. The traveling wave excitation (α=1.0) leads to a VIV response that 'grows' as it traverses the power-in region, in this case moving from the center towards either side where the presence of strakes creates strong power-out regions.