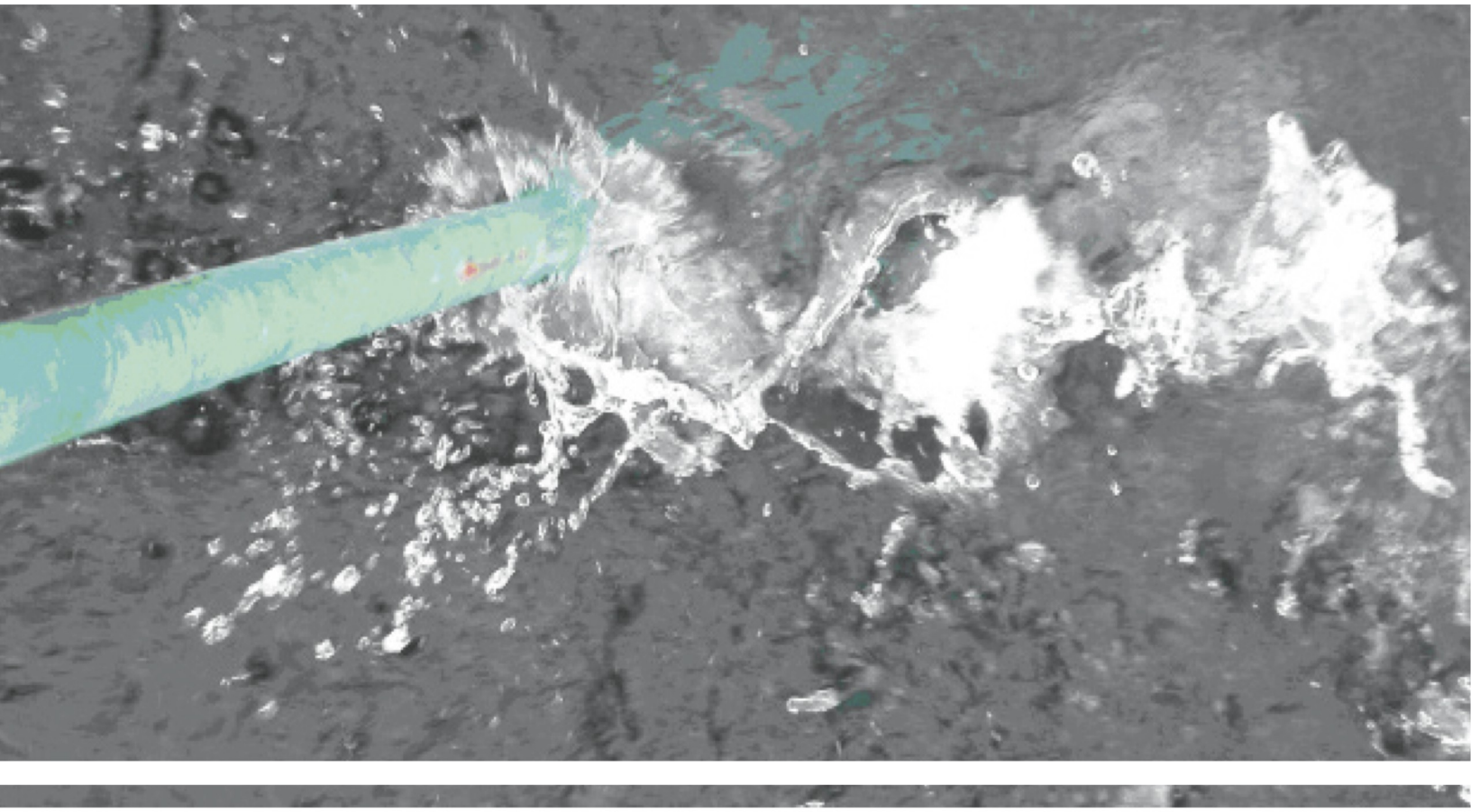
shear7

User Guide for SHEAR7 Version 4.10b



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1 SUMMARY OF NEW FEATURES IN VERSION 4.10

1.1 NEW IN VERSION 4.10B

1.1.1 Bug Fixes

- A scenario was uncovered where the first mode was marked as potentially excited even though it was outside the shedding frequency range. For this particular scenario the bandwidth factor was being double counted to further extend the shedding frequency range, which captured the first mode as potentially excited.
- Due to a minor inconsistency in the equations used for determining the potentially excited modes, and power-in and power-out regions, a scenario existed where the largest potentially excited mode (number) may not have been marked as potentially excited.
- The highest and lowest Strouhal frequencies reported in section 7 of the .out file do not have reduced velocity bandwidth factors applied, which returns the output to its v4.9 state.
- Allow the power-in region of an excited mode to be comprised of a single node.

These bugs were resolved in version 4.10b.

1.1.2 Academic License

SHEAR7 is now available under an Academic License. The Academic License requires a separate license dongle and executable.

- The Academic License is provided with the following input limitations:
  - Overall Length limited to 800 m or 2624 ft (refer to section 5.3.2)
  - Limited to one S-N Curve (refer to section 5.5.1)
  - Limited to one S-N curve segment (refer to section 5.5.2)
  - Limited to one Local SCF (refer to section 5.5.6)

Please contact the SHEAR7 Support Team for additional information on the Academic License, including license terms.

1.2 NEW IN VERSION 4.10A

1.2.1 Theoretical Improvements

- This release of SHEAR7 includes a significant improvement to the modelling of spatially varying damping, resulting in a more accurate response prediction, particularly in regions outside of the excitation zone. This feature is referred to as non-orthogonal damping and is activated with a new line item to Block 5 of the *.dat* file (section 5.6.19).

- When using non-orthogonal damping the beta control number (section 5.6.7) should be set to a non-zero value.
- To ensure an adequate number of modes is used for the mode superposition, the number of superposition modes was modified from 1.5 times the maximum vortex shedding frequency to 4 times the maximum potentially excited mode number. Users may be required to include more modes in any user generated *.mds* files used with previous versions of SHEAR7.

- The definition of A^* has been revised based on recent research findings. A^* is defined as the spatial RMS value of the temporal RMS response amplitudes in the power-in region, normalized by the reference diameter.

1.2.2 Bug Fixes

- For certain values of the reduced velocity bandwidth, the calculation of the highest and lowest Strouhal frequency would not use the reduced velocity bandwidth specified by the user.
- The minimum number of spatial segments is based on the minimum excitation wavelength and the largest potentially excited mode. The *.out* file reported inconsistent results for the minimum wavelength and the required number of spatial segments.
- If SHEAR7 detected the mode shapes in a user supplied *unique-name.mds* file (calculation option 3) were not normalised, SHEAR7 would automatically normalise the values. To be consistent with calculation option 2 (section 5.6.1) this function has been removed.
- Zones with large mass ratios would cause format overflow errors in section 4 of the *.out* file. The mass ratios are now reported in scientific notation.

These bugs are fixed in version 4.10a.

1.2.3 Error Handling

- All SHEAR7 errors result in a non-zero exit status.
- All error messages are directed to standard error (stderr). Normal operation output are still direct to standard out (stdout).
- Users are no longer required to press ENTER to continue when a license dongle error is raised, the program automatically exits.

1.2.4 I/O Handling

- Prompting for the input file continues until a filename is provided. CTRL + C can be used to abort the program.
- The input filename can be passed with or without the *.dat* extension. Previously the *.dat* extension could not be included when calling SHEAR7.

- The input echoing to the *.out* and *.scr* file has been standardised to produce the same results.

1.2.5 Input Validation

The reading of the input *.dat* file has been expanded to include the following validation checks:

- Raise an error if the structural model is 999 when trying to run calculation option 1.
- Raise an error if the inner strength diameter is greater than the outer strength diameter.
- Raise an error if there is no non-zero current supplied in the *.dat* file. Note: This check is not performed if running calculation option zero [only calculating natural frequencies].

1.2.6 Runtime Options

The following command line options have been added:

- **-t** : display the analysis run time in seconds.
- **-nologo** : the version information header is not displayed.

1.2.7 Regression Tests

- The regression test suite has been expanded both in breath and quantity, in order to extend the verification checklist to include the newly added features and fixes to the bugs.
- The regression suite has been separated into regression tests and fault insertion tests.

1.2.8 Changes To The Input *.dat* File

- As a result of the above theoretical improvements, the SHEAR7 input *.dat* file has changed. A program called “convert_v49_to_v410.exe” is provided with SHEAR7 Version 4.10, which will convert Version 4.9 input files to Version 4.10 input files.
- Complete details of the *.dat* file is presented in Section 5.

2 SUMMARY OF NEW FEATURES IN PREVIOUS VERSIONS

2.1 NEW IN VERSION 4.9B

2.1.1 Theoretical Improvements

- The definition of U_f has been revised based on recent research findings. U_f is defined as the RMS of the current speed in the power-in region for the excited mode.
    - Note that U_f is used in the calculation of c_f^*.
    - Please note, the parameters A_f^*, c_f^* and U_f are part of ongoing research. These parameters are intended to be interpreted in the context of being an ongoing Research and Development activity. A_f^* and c_f^* are calculated using the reference diameter which is specified by the end user in Block 5.

2.1.2 Bug Fixes

- Refinement of the convergence criteria applied to the beta iterations to resolve a bug causing the beta iteration for particular cases to cease after one iteration when convergence had not been reached. The beta iteration convergence tolerance was also decreased from 0.05 to 0.01.
- Fixed a bug in Section 11 of the .out file where the U_f values were reported as U_f^2.
- Resolution of a memory allocation bug when the number of modes was greater than the number of nodes.

2.1.3 Processing Enhancements

- SHEAR7 now supports the three Windows versions of Windows 7, Windows 8, and Windows 10.
- SHEAR7 is now compiled as a 64 bit program to improve memory allocation and overall performance.
    - A 32 bit version of the program is included as part of the standard installation to provide compatibility for users with 32 bit versions of Windows.

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 modelled. Structures are not required to be of constant cross-section, if a structure is to be modelled with a non-constant cross section the user is required to import the .mds file from a Finite Element package. The user may also model sections of structures with VIV suppression devices, fairings or staggered buoyancy modules.

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 LIMITATIONS

SHEAR7 is a mode superposition program and is not well suited to structures with large numbers of participating modes. Historically, there was a limit of no more than 100 participating modes be used. However, recent tests indicate that for long, slender and lightly damped structures higher numbers of modes may be used. In a previous release, SHEAR7 version 4.7, the maximum number of modes was increased to 1000 to facilitate higher mode number participation. 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 *.dat* 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).

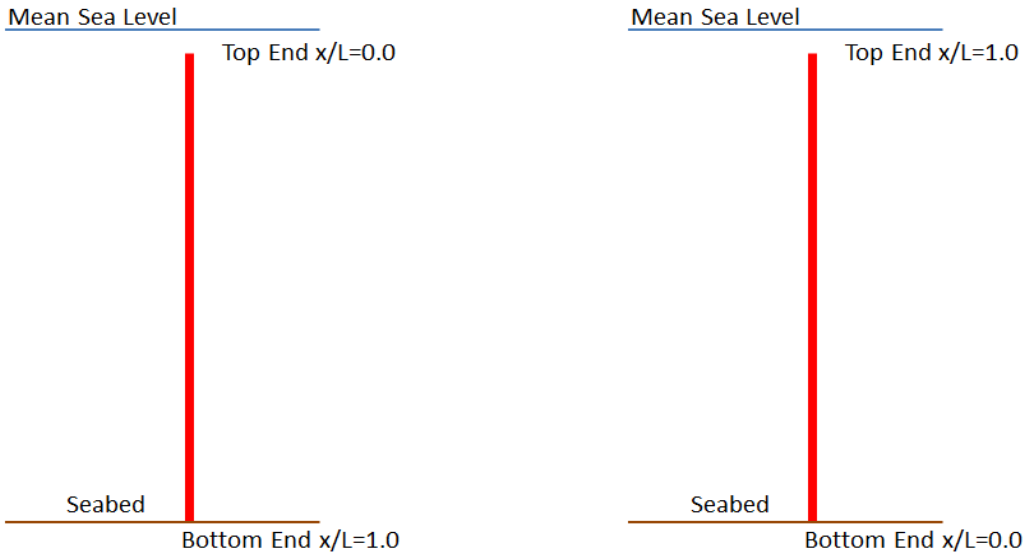


Figure 1: SHEAR7 Coordinate System

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 7, Windows 8 and Windows 10.

Please note, SHEAR7 no longer supports Windows XP as Microsoft has ended extended support for this Operating System.

Please note the following SHEAR7 guidance instructions:

- 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.CL** 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:

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

4.1 32 AND 64 BIT EXECUTABLES

SHEAR7 is provided as both 64 bit and 32 bit versions of the executables. After installation these are located within "<InstallationDir>\Bin".

- The 64 bit version is named **shear7_4.10b.exe**.
- The 32 bit version is named **shear7_4.10b_x86.exe**.

It is recommended to use the 64 bit version. The 32 bit version is provided to ensure compatibility for any users using a 32 bit system, as the 64 bit executable will not run on a 32 bit system.

4.2 REGRESSION TESTS

A series of regression tests are also provided with the software to ensure it is installed and operates correctly. The following steps outline the regression testing procedure:

- Use Windows Explorer to navigate to folder "<InstallationDir>\Regression Testing".
- Copy folder "Regression Testing" to your working folder (e.g. Desktop or Scratch drive).
- Copy the SHEAR7 executable from “<InstallationDir>\Bin” to this Regression Testing folder.
- Double click on the **s7regtester.exe** file located within the new copied folder and following the prompts.

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

5 SPECIFICATION OF INPUT DATA

The SHEAR7 input file is written as a text file and saved as a *.dat* 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.dat*") 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 4.10 as compared with version 4.9. Deletions of existing formats are shown as ~~abcdefgh~~ while new items added start with the word NEW:

SHEAR7 4.10 Data File For A Tensioned Beam With Boundary Rotational Spring	
File Name: basic_beam_3.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/ft³)
0.0000140	kinematic viscosity of the fluid (ft²/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(ft⁴), 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	0.3		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
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 *.scr file, (1=y;0=n)
0			flag for generating *.dmg file, (1=y;0=n)
0			flag for generating *.fat file, (1=y;0=n)
0			*.out file selection, (0=*.out, 1=*.out1, 2=*.out1+*.out2)
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 *.str file, (1=y;0=n)
NEW: 1			flag for non-orthogonal damping (1=y;0=n)
*** 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)

Note: Version 4.9 .dat files may be converted to version 4.10 by using the program convert_v49_to_v410.exe, which is provided with the program.

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.

The example data files are also conveniently summarized in a pdf file, “EXAMPLES-v4.10_rev0.pdf”, which is distributed with the program.

5.1 VERSION CONTROL

The first string of the first line within the input .dat file must be “SHEAR7 4.10”. 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 4.10 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	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

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 .out 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.dat
		1	Pinned-pinned beam, origin at minimum tension end	basic_beam_2.dat basic_beam_1.dat
		2	Free-pinned beam, origin at free end	-
		6	Pinned-pinned beam with two rotational springs[1]	basic_beam_3.dat
		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.dat
E	Use of a .mds file	999[2]	.mds 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 .mds 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 .out 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 16 of the .out 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 5.3.9.6.

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.

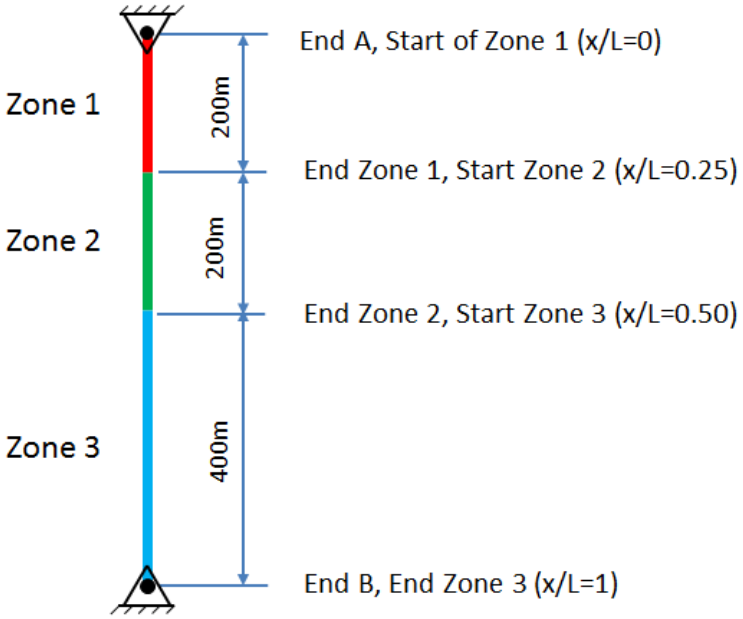


Figure 2: Example of Zone Start and End Point in x/L

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.

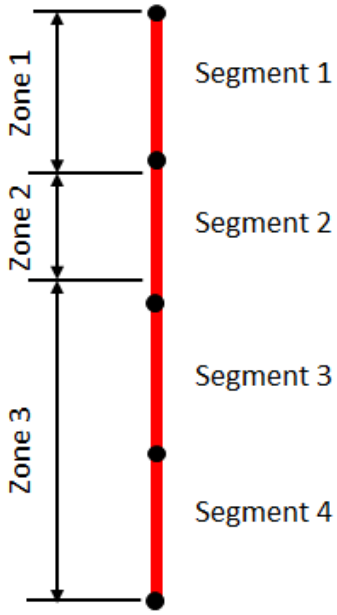


Figure 4: Example 2 of Incorrect Segment Allocation

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 outer 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 modelling 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.

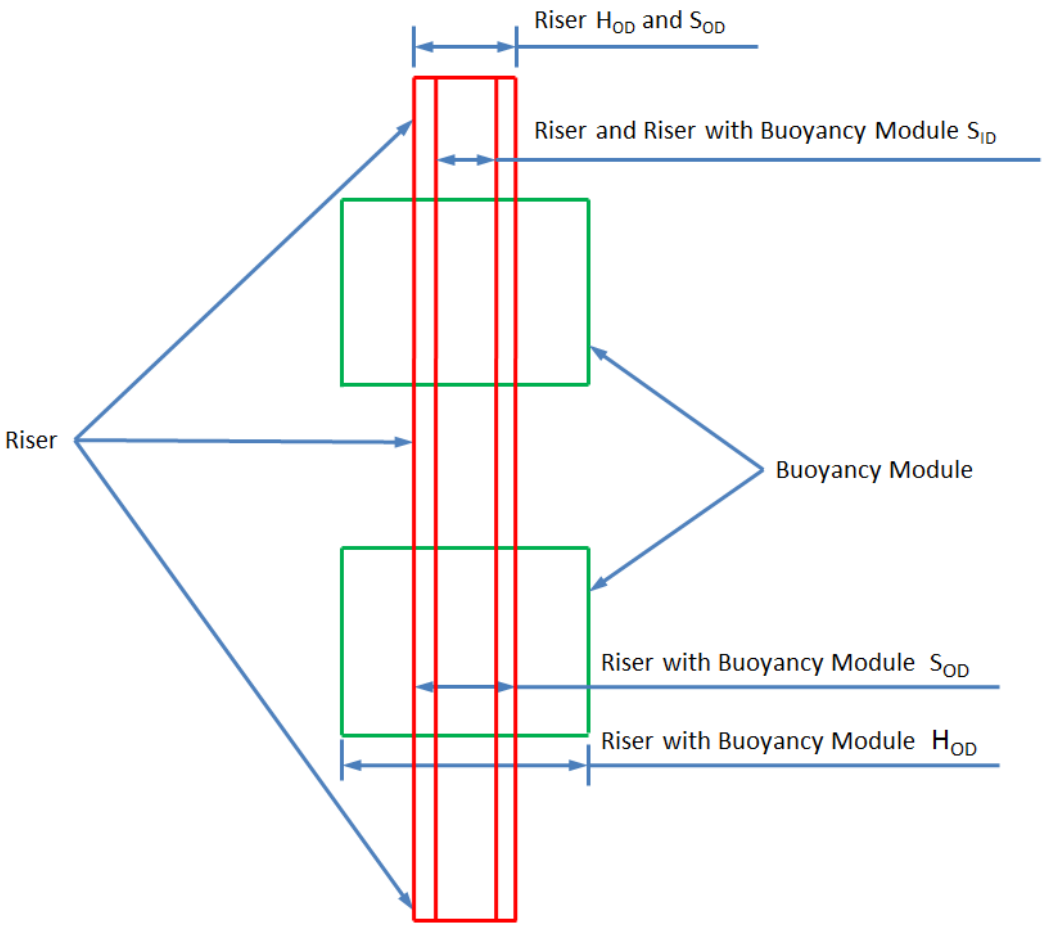


Figure 5: Example of Diameters in a Riser with Buoyancy Module Sections

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 modelling 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.

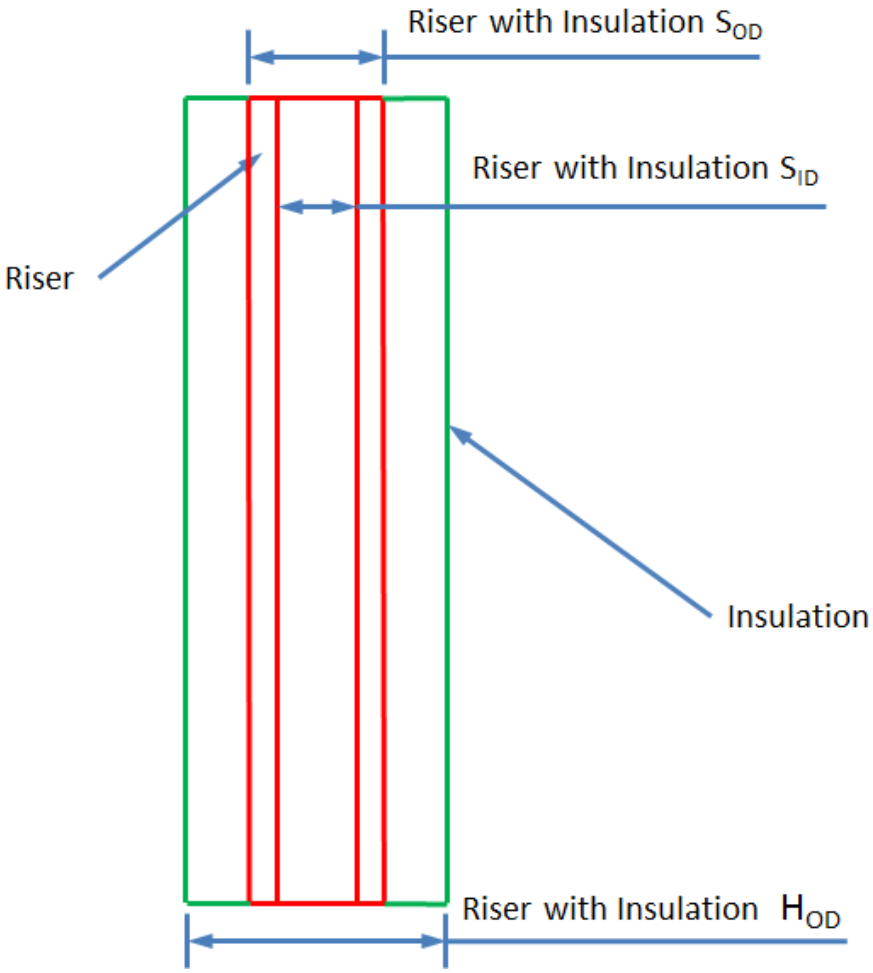


Figure 6: Example of Diameter in a Riser with Insulation Section

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 .out 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 .mds file from another program the *inertia* value is not used in the SHEAR7 analysis. See Section 5.8 for a complete list of input parameters not required when importing an .mds 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 .out 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 .dat 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.

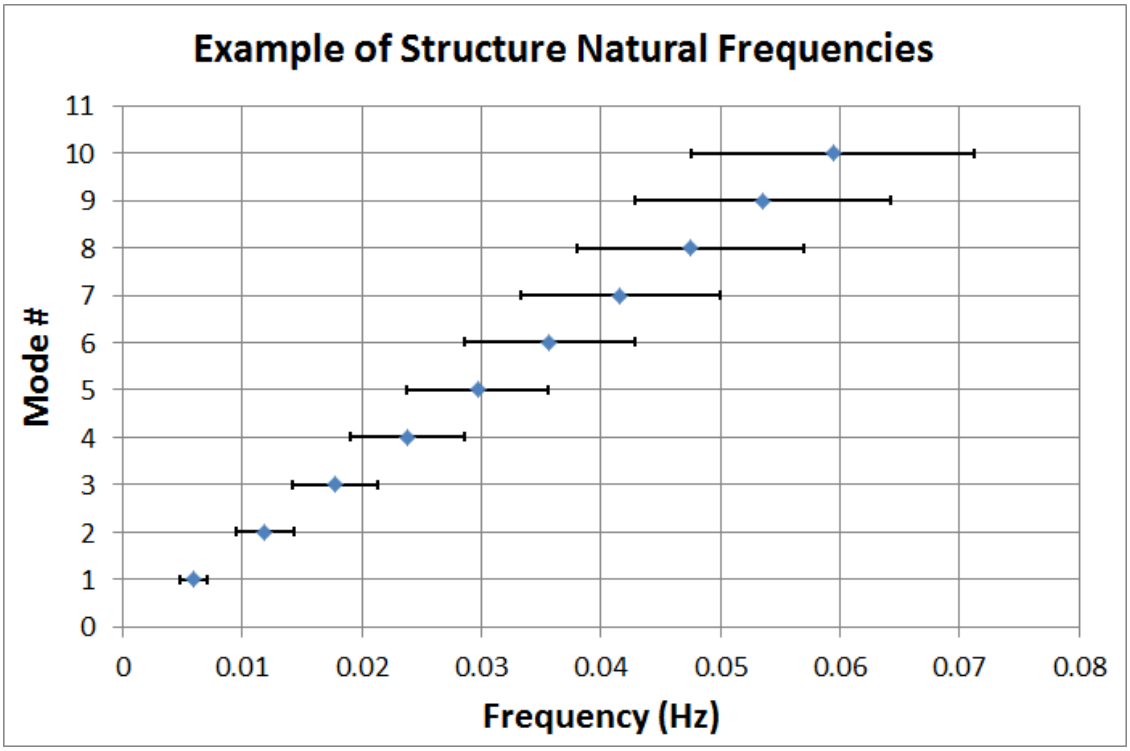


Figure 7: Example of Structure Natural Frequencies

- 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 *.out* 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.cl* table. 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	Cross-flow	Strake	Extremely conservative approximation to a riser with strakes. Conservative Default Values of lift coefficient for a cylinder with clean undamaged strakes
4	Cross-flow		Supplied as a dummy table for users to change
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		Supplied as a dummy table for users to change
7	In-Line	Bare	In-line excitation model which will over estimate that of Table 8
8	In-Line	Bare	In-line excitation model

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 3. 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.

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:

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

(ii) 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.

(iii) 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:

(i) 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 .out file:

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

(ii) 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)

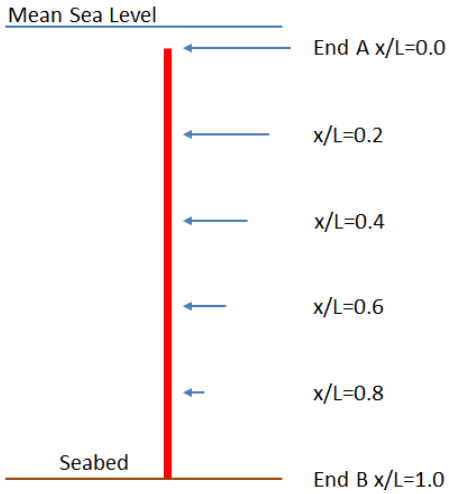


Table 8: Current Definition – Example 1 (x/L Convention Reversed)

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)

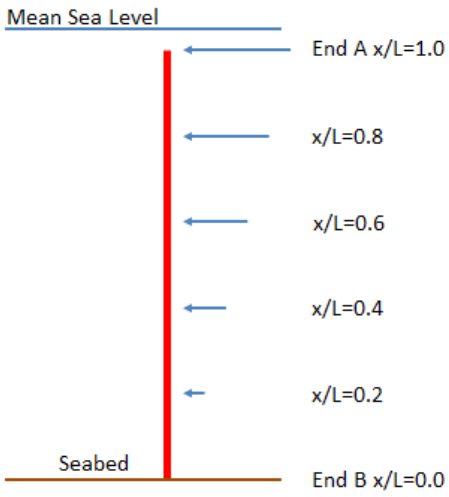
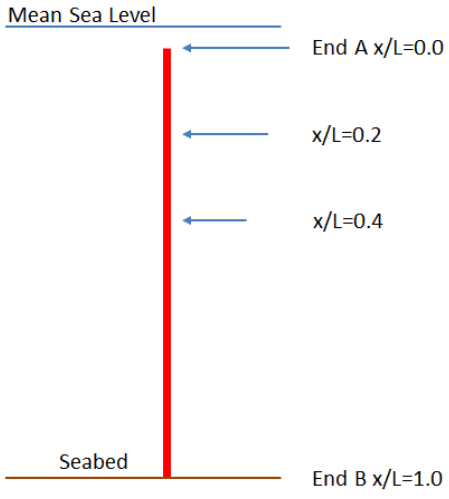


Table 9 presents the structure with both ends in the water and current applied to 40% of the structure length. This means that the entire structure length will account for hydrodynamic damping and added mass.

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)

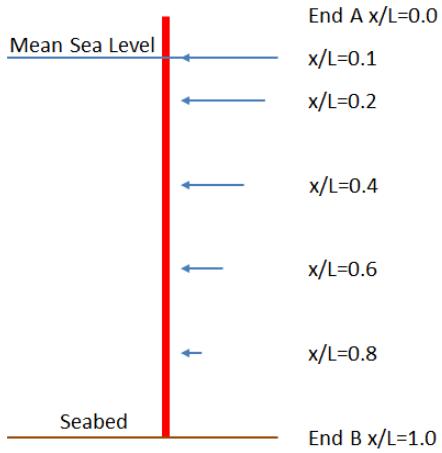
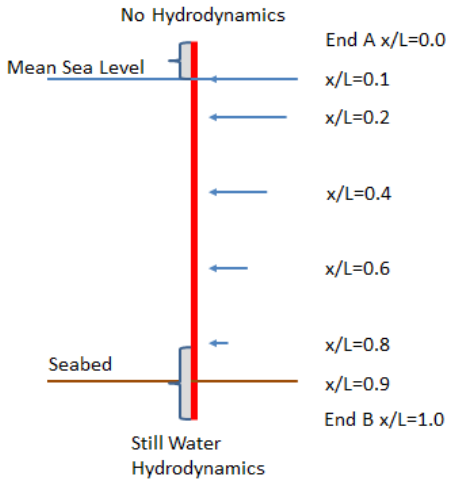


Table 11 presents the structure with one end out of the water and one end buried in the seabed with current applied to 70% of the structure length. This means that 90% of the structure length will account for hydrodynamic damping and added mass. From x/L=0 to x/L=0.1 the structure is out of the water, 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 .dat 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 33.

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	0.3		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
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 *.scr file, (1=y;0=n)
0			flag for generating *.dmg file, (1=y;0=n)
0			flag for generating *.fat file, (1=y;0=n)
0			*.out file selection, (0=*.out, 1=*.out1, 2=*.out1+*.out2)
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 *.str file, (1=y;0=n)
NEW: 1			Flag for non-orthogonal damping (1=y;0=n)

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.mds** 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.mds**) and then perform VIV analysis.

- Option 2 Uses externally prepared structural natural frequencies and mode shapes placed in a file called **common.mds**. 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 .mds 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.mds 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.mds** 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 files specified in Block 2. A list of the SHEAR7 used inputs relied upon for calculation Option 2 and 3 is presented in Section 5.8.

When using calculation Option 2 and 3, SHEAR7 will use all the modes in the .mds 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 .mds file.

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 *.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 .out 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 .out 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 .out file will be presented.

It should be noted that the location for output summary does not affect the .plt 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 .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 attenuates as it travels 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 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.

This user-specified value for this amplitude limit must have a value between 0 and 1.0 the default value is 0.3, for the present. The larger the value, the larger secondary zones will be, and more likely secondary power-in regions 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, but a reasonable value to choose for this limit is 0.3, which is to say that when the dynamic response from the dominant mode excitation region decays to 30% 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 set in the .dat 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.

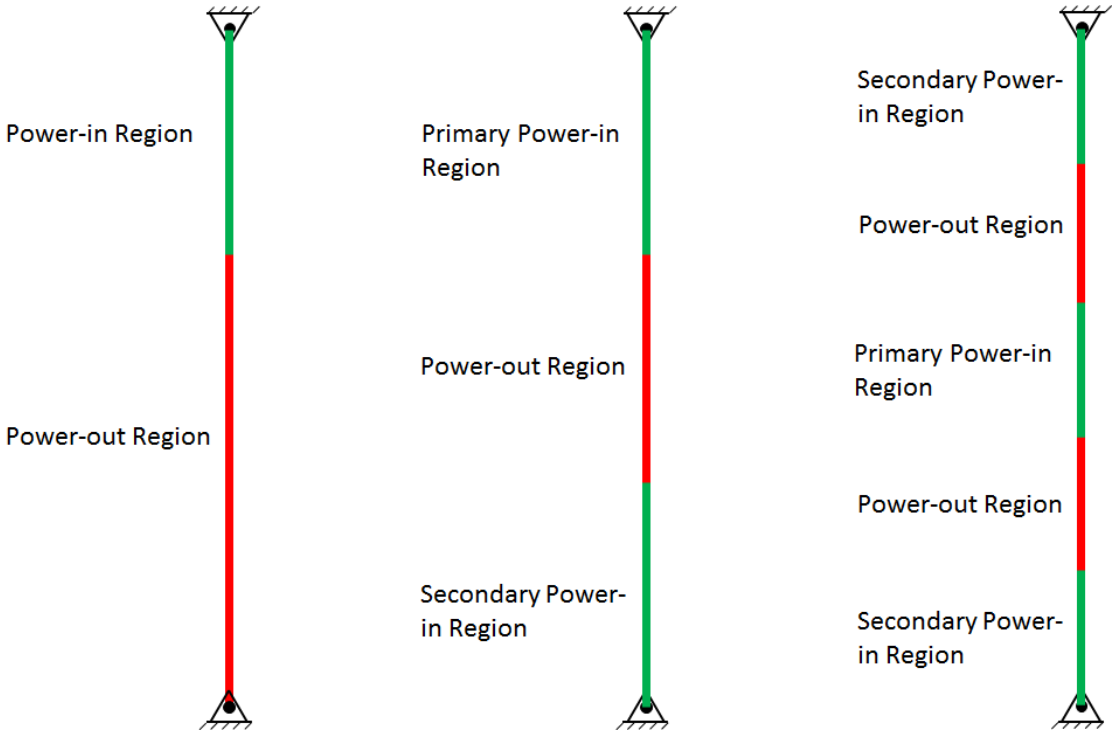


Figure 8: Possible Excitation Zones

Power-in regions located close to that of the dominant 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 primary mode.

Power-in regions where the amplitude 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.

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 σ_{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.
  - α is the Higher Harmonic Amplification Factor.

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

5.6.7 Beta Control Number

This value specifies the upper limit on the number of iterations that SHEAR7 will use to calculate beta, 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.

5.6.8 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.

5.6.9 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.

5.6.10 Import Common.cat

The **common.cat** file is not required when importing natural frequencies and mode shapes. This line defines whether the **common.cat** is required for the VIV analysis. The **common.cat** 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. Two possible values can be entered in this line as follows:

- 0 – Common.cat **is not** required for the analysis.
- 1 – Common.cat **is** required for the analysis.

This option should only be used when SHEAR7 is generating the .mds file.

5.6.10.1 Common.cat Specification

The **common.cat** input data file contains externally provided tension and mass per unit length data for each node. The number of nodes specified in the **common.cat** file must be one greater than the number of spatial segments (section 5.3.3) in the input .dat file. There are three (3) columns required in the common.cat file:

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

An excerpt from the **common.cat** file, provided to run example file **scr_import_tension.dat,** is presented in Table 14.

Table 14: Common.cat Example

1	16560	3.49485
2	17252.16992	3.49485
3	19644.23828	3.49485
4	25114.49805	3.49485
5	18115.56055	3.49485
...	...	...
199	94672.63281	3.49485
200	95140.54688	3.49485
201	95613.125	3.49485

5.6.11 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 *.anm* file. Two possible values can be entered in this line as follows:

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

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

5.6.12 Flag For .scr File

In normal execution of the program, it is not recommended to produce the .scr file. The *.scr* 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 *.scr* file
- 1 – SHEAR7 **will** report the *.scr* file

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

5.6.13 Flag For .dmg File

The *.dmg* 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 *.dmg* file
- 1 – SHEAR7 **will** report the *.dmg* file

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

5.6.14 Flag For .fat File

The *.fat* 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 .str file. Two possible values can be entered in this line as follows:

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

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

5.6.15 Flag For .out Or .out1 And .out2 Files

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

The *.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 *.out* file .See Section 7.8 for further description of the *.out1* file.

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

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

- 0 – SHEAR7 will report the *.out* file
- 1 – SHEAR7 will report the *.out* and *.out1* files
- 2 – SHEAR7 will report the *.out, .out1* and *.out2* files

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

5.6.16 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 .out and .plt 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.

5.6.17 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 .out file that in-line fatigue damage is being calculated. Selecting 0 runs SHEAR7 for cross-flow.

5.6.18 Flag For .str File

The *.str* 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 *.str* file.
- 1 – SHEAR7 **will** report the *.str* file.

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

5.6.19 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 modelling of spatially varying damping, resulting in a more accurate response prediction, particularly in regions outside of the excitation zone. 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 5.6.7) should be set to a non-zero value.

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 15: 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 15 are rotational spring constants as used in example basic_beam_3.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 .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 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 16.

Table 16: 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 *.out 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	

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.cl** file). Double click on the executable and respond to the prompt to enter the **root-name** of the *.dat* 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_4.10b.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_4.10b.exe basic_beam_1
shear7_4.10b.exe basic_beam_2
shear7_4.10b.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 c**ommon.cl**, **common.cat** and the **common.mds** files should be in the same directory as the **rootname.dat** files. The output files always accumulate in the same directory as the input .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 installation package copies both 32 and 64 bit versions of the executables. The 64 bit executable is named **shear7_4.10b.exe** and the 32 bit executable is named **shear7_4.10b_x86.exe**.

It is recommended to use the 64 bit version. The 32 bit version is provided to ensure compatibility for any users using a 32 bit system, as the 64 bit executable will not run on a 32 bit system.

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.dat**. This file is always required.

A second mandatory input data file is the **common.cl** file. The **common.cl** file included with the program distribution has several tables of lift coefficient. The user can add to the **common.cl** file custom built tables of lift coefficients. This file is always required.

When calculation Option 2 is used the program expects to find a file named **common.mds**. 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 *.dat* 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.cat**. The preparation of this file is described in the discussion of input data under Section 5.6.10.

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 17.

Compiler options can appear in any order, however they must all appear **after** the .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 17: 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, *.out*, *.plt, and .mds.* The *.mds* file will not be generated if using a user defined *.mds* file.

Additional, optional output files, (*.anm, .scr, .dmg, .fat, .out1, .out2 & .str*) can be created when specified by the user. See example scr1.dat and the description given later in this section. Each of the output file types is described below.

7.1 ROOT-NAME.OUT (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.dat". The output file "basic_beam_3.out" 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.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) 0.3233E+01 mass (lb/ft) 2296.140 sbmg wt (lbf/ft)  166.87
   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/sec**2):  0.000
   cutoff to eliminate modes:  0.0500
   primary zone amplitude limit:  0.3000
   power value exponent used:  1.0000
   higher harmonic amplification factor used:  3.3300
   higher harmonic threshold used:  0.4000
   Beta control number:    4
   Diameter type (inner or outer) used for stress computation:    0
   Reference diameter used for Af* and cf* computation:  84.0000 inches.
   flag for importing nodal tension & mass:   0   no
   flag for MATLAB animation data output:     0   no
   flag for generation *.scr file output:     0   no
   flag for generation *.dmg file output:     0   no
   flag for generation *.fat file output:     0   no
   flag for generation *.out file output:    0   *.out
   flag for calculating fatigue with zero-crossing method:    0   no
   flag for calculating first mode in-line fatigue damage:    0   no
   flag for .str file output:    0   no
   flag for non-orthogonal damping:    1    yes

*** BLOCK 6. supplemental data ***
   rot stiffness at x=L: 0.10000E+07 lbf-ft/rad
```

rot stiffness at x=0: 0.10000E+07 lbf-ft/rad.

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
0.10000E+01	0.11000E+01	0.30000E+00	0.70000E+00	0.30000E+00	-0.10000E+01

Next in every *.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 = 0.229E+00
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 Modes in excitation bandwidth, natural frequency,
modal ranking ratio, mode participation factors:
F = force; L = length; T = time.

mode no.	frequency (Hz)	modal force (F)	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	0.107E+05	0.000E+00	0.00000	0.000E+00
2	0.0426	0.105E+04	0.586E+04	0.936E+02	0.02886	0.289E-01
3	0.0788	0.321E+04	0.529E+04	0.975E+03	0.30074	0.301E+00
4	0.1277	0.601E+04	0.557E+04	0.324E+04	1.00000	0.100E+01

No. of potentially excited modes: 3

Section 2.2 is a result of one of the most important steps in the program's VIV modelling. 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.

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 and the power cutoff value of: 0.05 the number of modes above cutoff is: 2

These modes are:	Time Share Probabilities:	Excitation Zone #	Dominant Mode Amplitude:
3	0.2312	1	0.9548E+00
4	0.7688	1	0.1000E+01
	--------		--------

Cumulative sum: 1.0000 Primary zone amplitude limit: 0.3000

Lowest And Highest Excited Mode Number

Nmmin= 3 Nmmax= 4

Section 2.2.1 will apply the power cut of 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.

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 NUMBER # n	WAVE PROPAGATION PARAMETER n*zeta_n	Dominant_m to n# DISTANCE RATIO DelX/L	Dominant_m to n# MODE AMPLITUDE EXPONENT pi*zeta_m*m*|DelX|/L
3	0.1377	0.1163	0.0462
4	0.1256	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 ζ_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: 0.7152
   The bigger the ratio, the larger the variation in tension.

4. Structural Properties

zone	air mass slugs/ft	mass ratio	total mass slugs/ft	inertia ft**4	steel area ft**2	hydro area ft**2
1	0.714E+02	7.730E-01	0.148E+03	0.323E+01	0.192E+01	0.385E+02

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 = 0.017599(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 *.dat* file. For a uniform flow, the maximum and minimum current will be equal.

7. The highest Strouhal frequency is: 0.12163(Hz) at node: 5
The lowest Strouhal frequency is: 0.01929(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)
3	0.04592	0.13775	107301.07	0.07878
4	0.03163	0.12652	107434.28	0.12769

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 .out 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.	Modal Amp (ft or m)	A_rms/D_ref	c*	Uf	Beta
3	2.77276	0.2332E+00	0.1529E-01	0.3005E+01	1.06442
4	3.35879	0.3077E+00	0.1094E-01	0.4209E+01	1.02789

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. 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 .out file. This is because the final response amplitude, even if at only one frequency, includes the contributions of resonant and non-resonant modes.

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 .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 values reported are the values calculated after the final iteration. When the beta control value is set to 0 in the input .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 *.scr* file.

13. Beta iteration for each mode.

Iteration	Mode	Beta
0	3	1.061392
0	4	1.027334
1	3	1.064419
1	4	1.027887

For multiple modes, the convergence criteria is applied
to each excited mode, using a threshold value of 1.0E-02.

Section 13 presents the beta values calculated after each beta iteration. The beta values for a particular mode should be converging as the iterations progress. For multi mode cases, SHEAR7 stops the iterations when the 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 .dat should be set to zero.

14. Lift coefficient for each mode.
In the following, the lift coefficient 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	Cl	Fn/Fvo	VR
18	0.6856	0.8119	6.84
19	0.6869	0.8431	6.59
20	0.6890	0.8767	6.34
21	0.6916	0.9132	6.08
22	0.6945	0.9528	5.83
23	0.6971	0.9961	5.58
24	0.6991	1.0434	5.32
25	0.7000	1.0955	5.07
26	0.6967	1.1530	4.82
27	0.6847	1.2169	4.57
28	0.6620	1.2723	4.37
29	0.6271	1.2938	4.29
30	0.5786	1.3160	4.22

mode number: 4

node number	Cl	Fn/Fvo	VR
5	0.6824	1.1548	4.81

6	0.6995	1.1551	4.81
7	0.6986	1.1554	4.81
8	0.6934	1.1557	4.81
9	0.6860	1.1559	4.81
10	0.6780	1.1562	4.80
11	0.6709	1.1565	4.80
12	0.6658	1.1568	4.80
13	0.6635	1.1571	4.80
14	0.6643	1.1574	4.80
15	0.6681	1.1845	4.69
16	0.6743	1.2252	4.53
17	0.6820	1.2689	4.38
18	0.6899	1.3159	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. They include all applied factors such as the lift coefficient reduction factor. Also tabulated in the third column is the normalized frequency ratio, as used in the .CL table. The fourth column gives the local reduced velocity at each node.

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

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

15. RMS response and damage rate at specified locations.

Modes used in mode superposition calculation are from mode 1 to mode 13.

English units: displacement = feet; 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	0.777E-01	0.144E-05
0.100	2.155	0.308	0.131E+01	0.863E+01	0.714E+02
0.200	1.503	0.215	0.805E+00	0.524E+01	0.939E+01
0.300	1.390	0.199	0.875E+00	0.561E+01	0.152E+02
0.400	2.018	0.288	0.124E+01	0.797E+01	0.544E+02
0.500	0.970	0.139	0.292E+00	0.240E+01	0.742E+00
0.600	2.068	0.295	0.130E+01	0.811E+01	0.595E+02
0.700	1.166	0.167	0.719E+00	0.445E+01	0.615E+01
0.800	1.581	0.226	0.865E+00	0.545E+01	0.113E+02
0.900	2.084	0.298	0.127E+01	0.772E+01	0.476E+02
1.000	0.000	0.000	0.000E+00	0.375E-01	0.785E-07

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 *.dat* 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	0.160	0.894E+00	0.07878
4	0.120	0.817E+02	0.12769

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 *.plt* 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 2.278 ft
OMRD occurs at x/L= 0.130

15.4 The Overall Maximum RMS Stress (OMRS) is 8.993 ksi
OMRS occurs at x/L= 0.120

15.5 The Overall Maximum Fatigue Damage (OMFD) is 0.824E+02
OMFD occurs at x/L= 0.120

The overall maximum values given in 15.3, 15.4 and 15.5 above, result from searching every nodal point in the *.plt* 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 (lb)	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	1.761
0.200	274870.0	3.3550	1677500.0	0.180	1.602
0.300	299900.5	2.2883	1144141.6	0.180	1.572
0.400	324931.0	1.8891	944570.8	0.180	1.729
0.500	349961.5	1.4900	745000.0	0.180	1.453
0.600	374992.0	1.3885	694260.0	0.180	1.741
0.700	400022.5	1.2870	643520.1	0.180	1.511
0.800	425053.0	1.1856	592780.1	0.180	1.622
0.900	450083.5	1.0841	542040.2	0.180	1.745

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: 35

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.

7.2 ROOT-NAME.PLT (ALWAYS CREATED)

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

There are seven columns in the *.plt* file and they are described in Table 18. The units are also included in Table 18.

Table 18: 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.MDS

The *.mds* 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 "*.mds*" file consists of three blocks. The structure of the *.mds* file can be obtained by running one of the example *.dat* files and opening the created *.mds* file. An *.mds* file has three blocks of data as described below. An excerpt from the **common.mds** file, provided to run example file **drill_riser_ext_modes.dat,** is presented in Table 19, including the complete data for Blocks 1 and 2 and the first few lines of Block 3.

Table 19: .mds 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 .mds 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 20. 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.
- 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.mds 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 21.
- 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 20: MDS 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	1/m	-
English	-	-	ft	ft/ft	1/ft	-

Table 21: .mds 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.mds 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 .mds file prepared by FEA programs should follow the same convention as it is presented in Table 19 for even nodal spacing and Table 21 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 .out 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.mds 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.mds 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.mds file after running under Option 1.

It is noted, that when generating common.mds 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.mds or .mds file.

When using certain 3rd party FEA programs to generate the common.mds or .mds, 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 .mds 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.mds file to common.mds, 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 ROOTNAME.ANM

To enable creation of the *.anm* file a '1' should be entered next to "flag for MATLAB animation data output 1=yes;0=no)". *.anm* 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.SCR

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

The data is written to the *.scr* 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 *.scr* file.

The first blocks of the *.scr* file contain an echo of the input data. The input echoes are written to the *.scr* file almost immediately after the input has been read by SHEAR7. When the program stops before writing anything in the *.out* file, the error may be identified by seeing at what point the input data echo stops in the *.scr* 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 22

Table 22: .scr 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 *.scr* file also gives tabular summaries of preliminary and final computations. An example excerpt from execution of an example file is shown in Table 23. 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 24. 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 23: .scr 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 24: .scr 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.DMG

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 .dmg file is presented in Table 25. 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 25: .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 *.out* and the *.plt* files the fatigue damage is multiplied by the time sharing probabilities listed in Line 2 of Block 1 of the *.dmg* file (same as those listed in Table 2.2.1 of the *.out* file). The results listed in Block 2 of *.dmg* are unfactored, so that the user can do independent post-processing.
- If zero-crossing fatigue calculation is used, the .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 .plt.
- An example of the .dmg file when the zero-crossing fatigue calculation is used is presented in Table 26.

Table 26: .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.FAT

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 seven columns in the .fat file and the respective units are presented in Table 27.

Table 27: .fat Columns

Units	Mode	Assoc	Freq	ModeAmp	ModePhase	ModeForce	ModeProb
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 .str file.

7.8 ROOT-NAME.OUT1

The reason for creating this file is to decrease the size of the *.out* file, in particular for high aspect ratio models, where many modes can be present. With the above flag set to default zero no *.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 *.out1* file. The *.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 *.out1* file output. The format is identical to that used in Item 14 of the *.out* file, whenever the *.out1* or the *.out1* and *.out2* files are not generated.

Table 28: .out1 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	Cl	Fn/Fvo	VR
5	0.692	0.8661	4.81
6	0.6998	0.8663	4.81
7	0.6954	0.8665	4.81
8	0.6867	0.8667	4.81
9	0.6758	0.867	4.81
10	0.6646	0.8672	4.8
11	0.6549	0.8674	4.8
12	0.6481	0.8676	4.8
13	0.645	0.8678	4.8
14	0.6461	0.868	4.8
15	0.6512	0.8883	4.69
16	0.6596	0.9189	4.53
17	0.6702	0.9517	4.38
18	0.6815	0.9869	4.22
19	0.6914	1.0248	4.07
20	0.6982	1.0657	3.91
21	0.6992	1.11	3.75
22	0.6772	1.1582	3.6
23	0.6205	1.2108	3.44
24	0.525	1.2683	3.29
25	0.3884	1.3316	3.13

7.9 ROOT-NAME.OUT2

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

The *.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 *.out2* file resembles those of the *.mds* and the *.dmg* files.

There are six columns in the .out2 file and they are presented in Table 29. The units for each are also shown in Table 29.

Table 29: .out2 Columns

Units	Mode Number	Node Number	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 .out2 file.

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

Table 30 presents an example of the .out2 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.

It is noted that requesting the printing of the *.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 30: .out2 Example

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

7.10 ROOT-NAME.STR

This 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 *.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 .str file is presented in Table 31. 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 31: .str 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 .str changes. The first line of the .str 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 .str file when the zero-crossing fatigue calculation is used is presented in Table 32.

Table 32: .str Example 2

Zero crossing method is used.		
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

8 .DAT FILE CONVERSION PROGRAM

A program for automatic conversion of SHEAR7 version 4.9 to 4.10 *.dat* files is provided. It is called **convert_v49_to_v410.exe**.

This program will convert all of the .dat files in a directory from version 4.9 *.dat* files to 4.10 .dat files. The names of the files are not changed. Therefore, if you want to retain the original version 4.9 *.dat* files then put a copy in a separate directory.

To use the program, the required *.dat* files should be dragged over the top of the **convert_v49_to_v410.exe** program then release.

The conversion program sets the non-orthogonal damping flag as 1 (on). The user needs to check the converted file to ensure the values used are appropriate for their modelling situation.

9 AVAILABLE EXAMPLES

The available SHEAR7 examples are presented in Tables 33 to 37. The SHEAR7 example .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 33: Basic Modelling Examples

File Name	Description	Units (flag)	Calculation Option	Structural Model				SN-Curve	SCF	Suppression	Beta Iteration	Non-Orthogonal Damping
				Code	Type	B.C	Tension					
basic_cable	cable response	English (1)	1	0	string	pinned-pinned	varying	ASME	1.0	no	4	1
basic_beam_1	response of tensioned beam	English (1)	1	1	beam	pinned-pinned	varying	API-X	1.0	no	4	1
basic_beam_2	response of tensioned beam	SI (0)	1	1	beam	pinned-pinned	varying	API-X	1.0	no	4	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	4	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	4	1

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

Table 34: Riser System Examples

File Name	Description	Units (flag)	Calculation Option	Structural Model				SN-Curve	SCF	Suppression	Beta Iteration	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	4	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	4	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	4	1
scr_inclined_cat	inclined catenary response	English (1)	1	33	Catenary	pinned-pinned	varying	API-X	1.0	no	4	1

Table 35: Time Sharing Function Examples

File Name	Description	Units (flag)	Calculation Option	Structural Model				SN-Curve	SCF	Suppression	Beta Iteration	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	4	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 .out file	English (1)	1	1	beam	pinned-pinned	varying	API-X'	1.0	no	4	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	4	1

Table 36: Strake Modelling Examples

File Name	Description	Units (flag)	Calculation Option	Structural Model				SN-Curve	SCF	Suppression	Beta Iteration	Non-Orthogonal Damping
				Code	Type	B.C	Tension					
strake_1	TTR with upper 85% strake coverage in GOM. Recommended strake modelling table (5).	English (1)	1	1	beam	pinned-pinned	varying	API-X'	1.0	yes	4	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	4	1

Table 37: Selected Benchmark Risers Examples

File Name	Description	Units (flag)	Calculation Option	Structural Model				SN-Curve	SCF	Suppression	Beta Iterations	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	4	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	4	1
benchmark_miami2_bare	Long flexible DeepStar field test riser - bare	English (1)	1	1	beam	pinned-pinned	varying	API-X'	1.0	no	4	1

Table 38: Jumper VIV Modelling 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 39
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 39
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 39
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 39

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 39: 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 MODELLING 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 .dat conversion program (Section 8) which will utilise 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 modelling 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 modelled 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.mds 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

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A.1 DEFAULT SHEAR7 PARAMETERS

The experimental results in laboratory and field tests have 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.
- 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 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 modelling 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 Higher Harmonics amplification factor and threshold can be important when modelling systems that result in Higher mode number excitation. When using the Higher Harmonics feature, the default threshold value is 0.4 and the default Higher Harmonics amplification factor is 3.33. 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

Property		Riser Region		
		Bare	Straked	Fairings
Added Mass		1.0	2.0	2.0
Strouhal Number		0.18	0.10	0.10
Bandwidth		0.40	0.25	0.00
CL Table		1	5	5
Beta Control Number		4	4	4
Damping Coefficient	Reynolds Number Still Water	1.00	1.00	1.00
	A/D Still Water	0.20	0.40	0.40
	Low V_R Regions	0.18	0.50	0.50
	High V_R Regions	0.20	0.20	0.40
	Axial Flow Regions	0.00	0.00	0.00
Power Ratio Cutoff		0.05	0.05	0.05
Primary Zone Amplitude Limit		0.3	0.3	0.3
Lift Coefficient Reduction Factor		1.0	1.0	1.0
Power Ratio Exponent		1	1	1
Non-Orthogonal Damping		1	1	1
If Higher Harmonics is Required				
Higher Harmonics Threshold		0.4	0.4	0.4
Higher Harmonics Factor		3.33	3.33	3.33

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 cognisant of these aspects.

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).

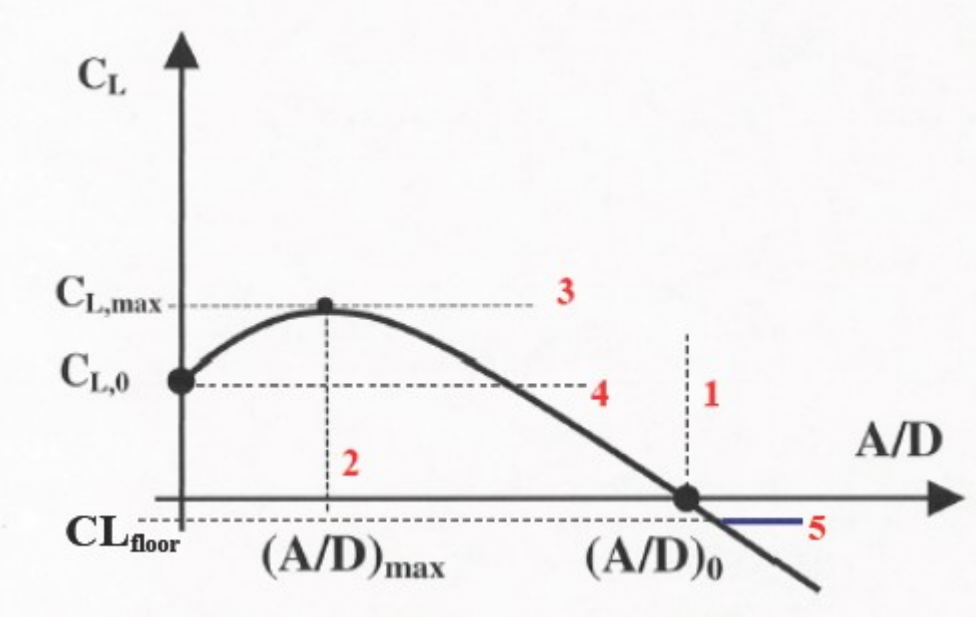

Figure 9: SHEAR7 defines a smoothed lift coefficient curve by fitting two parabolas to three defined by four user-specified values.

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 9.

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.cl 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 modelling. 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 9), 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.cl'* 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:

    A single curve, independent of frequency ratio, which was originally recommended to model strakes. This is a very conservative model of strakes, which is now considered obsolete.
  - C_L table4:

    This is a dummy table.
  - 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 are, but it is less conservative than C_L table3 is.

- ○ 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

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

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

- Figure 2 gives an example of the data contained in the *common.cl* file.
- The *common.cl* file must be in the same directory as the SHEAR7 program.
- The first block of the .cl 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:
  - Column 1:

    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.cl* 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

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Table C1: SHEAR7 Error Messages

Warning ID/Code Reference	Message Provided To User	SHEAR7 Halted (Yes/No)	File Output	Description
1	RUNTIME ERROR: You should use 0 (SI) or 1 (English) to choose a unit system.	Yes	.out	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 .dat file. The provided input .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 .dat file.
4	RUNTIME ERROR: The starting response location must be less than the ending location in your input.	Yes	.out	The end response location is smaller than the start response location specified in the 2nd line of the BLOCK 5 of input .dat file. See Section 5.6.2 for explanation of these terms.
5	RUNTIME ERROR: Incorrect step size for response location.	Yes	.out	The step size specified in the 2nd line of BLOCK 5 in input .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: Input step size is less than spatial resolution. It has been reset in the program.	No	.out	The step size specified in the 2nd line of BLOCK 5 in input .dat file is less than the spatial resolution specified in line 3 of BLOCK 2 in input .dat file. The user should increase the response step size.
7	RUNTIME ERROR: Flag to choose calculation option must be 0, 1, 2 or 3	Yes	.out	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 .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: To specify a current profile, x/L must be in ascending order. Your input is invalid.	Yes	.out	The current profile in BLOCK 3 of the input .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: The annual probability of occurrence should be no greater than 1.0. Your input is invalid.	Yes	.out	The 2nd value in the 1st line of BLOCK 3 in input .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: Program indicates that there is negative effective tension at node:	No	.out	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 .dat file used.
11	RUNTIME ERROR: The input number of modes: [number of input modes] exceeds the program capacity: [program capacity]	Yes	.out	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: The input # of nodes are not equal (as required). In the .dat file, you input: [number of .dat nodes] In the common.mds file, you input: [number of .mds nodes]	Yes	.out	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 .dat file.
14	RUNTIME ERROR: The maximum MDS mode number is: The maximum potentially excited mode number is: The modes supplied are not sufficient. Modes up to at least 4.0 times the maximum potentially excited mode number should be supplied.	Yes	.out	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: No VIV has been predicted. The maximum shedding frequency is below the fundamental natural frequency band. The program predicts that VIV may not occur. The minimum excitation frequency is: The maximum excitation frequency is: The first natural frequency is: The above frequencies are in rad/s	Yes	.out	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: No VIV has been predicted. This may be due to a very weak power-in and is insufficient to result in VIV.	Yes	.out	Based on the input parameters specified, no VIV was predicted.
18	RUNTIME ERROR: zero modal input power. check input data.	Yes	.out	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: mode shape calculation incorrect. zero mode shape and curvature.	Yes	.out	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: The maximum mode number is greater than the program-allowed: If you want to run this case, you should change the program-allowed maximum.	Yes	.out	The inbuilt modal calculation has generated more modes than the SHEAR7 mode count limit. Please consult with the SHEAR7 support team.
21	RUNTIME ERROR: You have requested more CL data than than is available in common.CL	Yes	.out	The CL table specified for at least one (1) of the zones in the input .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 .dat file and the common.CL file that is being used.
22	RUNTIME ERROR: You have stress-cycle data in non-increasing stress order	Yes	.out	Please see Section 5.5 for the required format of the S-N Curve data.
23	RUNTIME ERROR: Not a valid Strouhal number code to choose a unit system.	Yes	.out	Strouhal number codes are no longer supported in SHEAR7. See Section 5.3.9.5 for information on Strouhal number.
24	RUNTIME ERROR: The predicted dominant inline mode number is Mode 3 or higher. 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	.out	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: The number of spatial segments is less than the estimated minimum number required by SHEAR7. Number of spatial segments: Required number of spatial segments:	Yes	.out	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.
26	RUNTIME ERROR: The zone size from dat files is less than the length of the length of segment at this location.	Yes	.out	The length of at least one of the zones is shorter than the segmentation length. Potential resolutions are: Increasing the length of the offending zone(s) to be greater than the segmentation length; or Decreasing the segmentation length by increasing the number of segments.

Table C1: SHEAR7 Error Messages

Warning ID/Code Reference	Message Provided To User	SHEAR7 Halted (Yes/No)	File Output	Description
27	RUNTIME ERROR: No segments defined in mds file have been assigned to zone defined in dat file.	Yes	.out	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: Increasing the length of the zone(s) to be greater than the segmentation length; or Decreasing the segmentation length by increasing the number of segments.
28	RUNTIME ERROR: Local SCF has overwritten previous Local SCF Check Local SCF x/L positions in dat file.	Yes	.out	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: Adjusting the specified x/L position of the Local SCFs so that they are on nodal positions; or Decreasing the segmentation length by increasing the number of segments.
29	RUNTIME ERROR: Mode shape values in the user supplied .mds file must be normalised. Please check the .mds file	Yes	.out	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	.out	Based on the input parameters there is no VIV predicted.
50	INPUT ERROR: Flag for non-orthogonal damping must be 0 or 1.	Yes	.out	Please see Section 5.6.19 for the required format of the non-orthogonal damping flag.
61	LICENSE ERROR: Academic License only allows 8.00E+02m Structural Length This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program.	Yes	.out	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: Academic license only allows 2.624E+03ft Structural Length This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program.	Yes	.out	Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations.
61	LICENSE ERROR: Academic license only allows 1 S-N Curve This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program.	Yes	.out	Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations.
61	LICENSE ERROR: Academic license only allows 1 S-N Curve Segment This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program.	Yes	.out	Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations.
61	LICENSE ERROR: Academic license only allows 1 Local SCF This error is only relevant to the Academic License program and not the full commercial SHEAR7 licensed program.	Yes	.out	Please review input parameters to ensure the length, S-N curve and SCF inputs are within the license limitations.
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	.out	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	.out	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. Please correct in the *.dat. Program exits!	Yes	.out	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. Please correct in the *.dat or in the common.cl file. Program exits!	Yes	.out	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	.out	A CL table requested by the input file is less than 1. See section 5.3.9.5 for information on this input line.

Table C1: SHEAR7 Error Messages

Warning ID/Code Reference	Message Provided To User	SHEAR7 Halted (Yes/No)	File Output	Description
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 Please use less segments. Program exits!	Yes	.out	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 *.dat file, program exits! ERROR, zone S-N Curve I.D. specified for an undefined curve, program exits! ERROR, S-N Curve: non-consecutive I.D. numbering. Program exits!	Yes	.out	This identifies three errors related to the input S-N curves.
110	INPUT ERROR: Input error on line: line_num Expected inputs: message Fortran READ error: err	Yes	.out	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.
111	INPUT ERROR: The outer diameter must be greater than the inner diameter. Error in zone: zone_num	Yes	.out	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	.out	SHEAR7 requires non-zero current for VIV prediction. Note: This check is not performed if running calculation option zero (0).

APPENDIX D TUTORIAL / EXAMPLE

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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.dat' 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

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

SHEAR7 4.10: Data file for a tensioned beam with boundary rotational spring

File Name: basic_beam_3.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
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 *.scr file, (0=no;1=yes)
0                       flag for generating *.dmg file, (0=no;1=yes)
0                       flag for generating *.fat file, (0=no;1=yes)
0                       *.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 *.str file, (1=yes;0=no)
1                       flag for non-orthogonal damping (1=y;0=n)
*** 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)

APPENDIX E VIV TECHNICAL REFERENCES

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E.1 VIV TECHNICAL REFERENCES

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APPENDIX F EXCERPT OF VERSION 4.8 AXIAL FLOW DAMPING TERMS

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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 10. In a typical flow the total damping, ζ_n, of any node *n*, is the summation of the structural and hydrodynamic damping as per Equation 6 and 7.

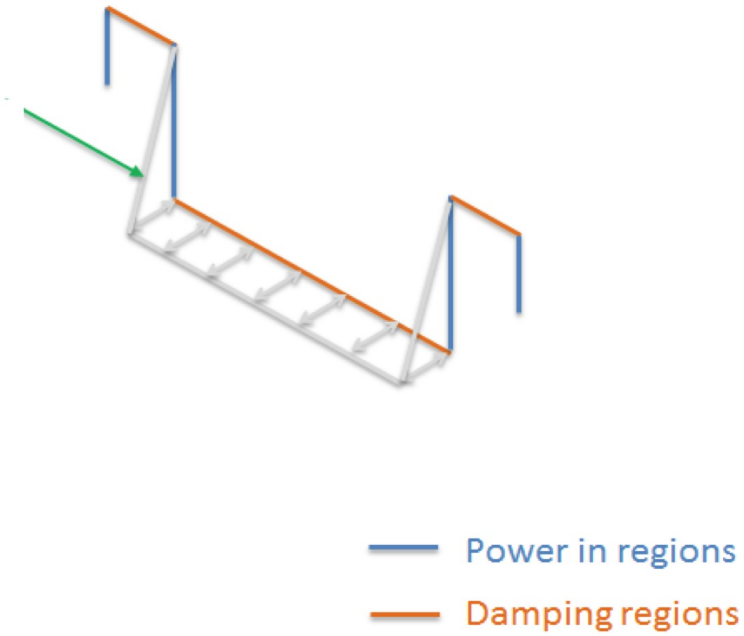

Figure 10: Jumper schematic highlighting power-in and damping regions when modelling axial flow

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

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

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 modelling 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 MODELLING USING SHEAR7

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G.1 IN-LINE MODELLING 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 11 shows a summary of the latest data of A/D limits where the value of CL = 0, plotted on top are the *common.CL 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.

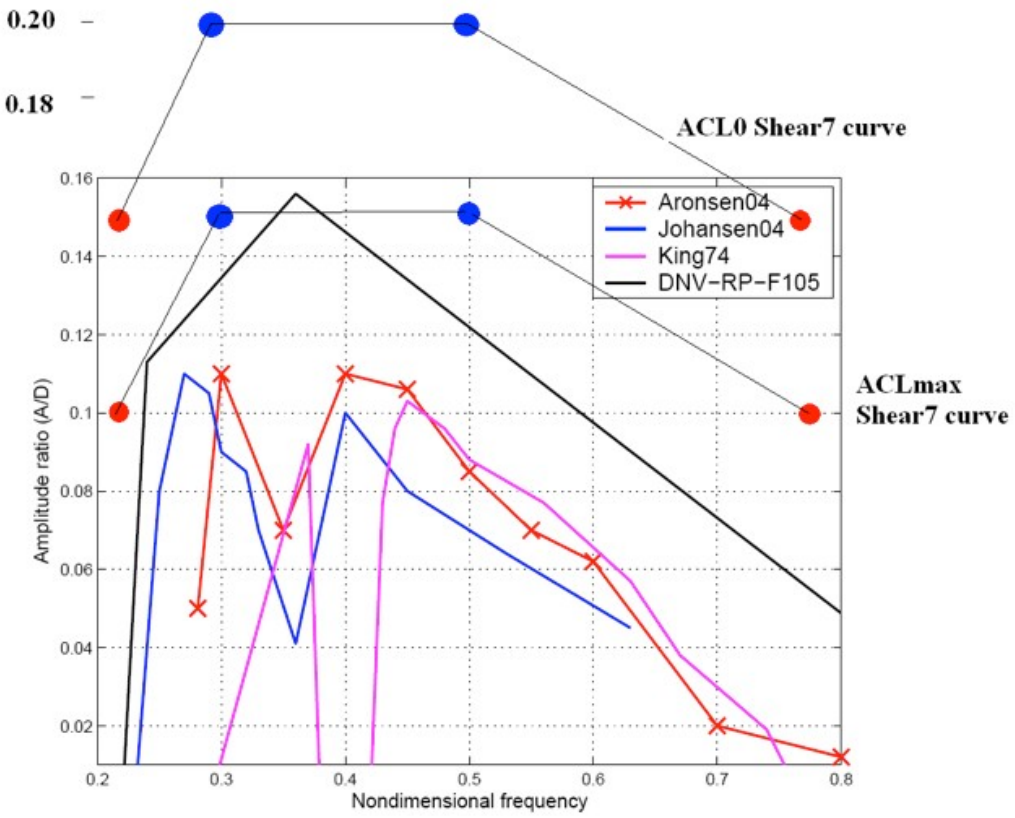

Figure 11: Summary of A/D at CL = 0 limits from Ref [1], along with limits of common.CL curves for *common.CL Table 7*

The lift coefficient values take the form of two different curves shown in Figure 12. 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.

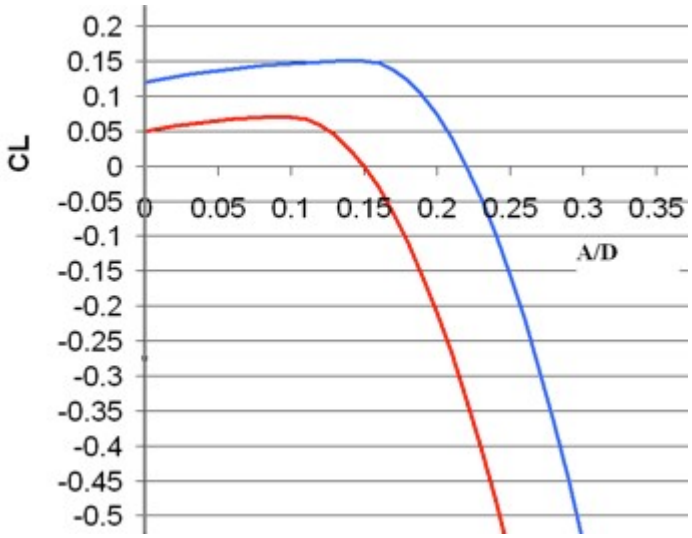

Figure 12: *common.CL curves for common.CL Table 7*

As shown in Figure 11 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.CL Table

The common.CL 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 Cltype → change to reference the correct table number in common.CL
4. Common.CL file → Add the new common.CL table to the common.CL 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 summarise 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 13 *common.CL Table 7* is the dashed line, *common.CL Table 8* the solid line and experiments are marked with crosses.

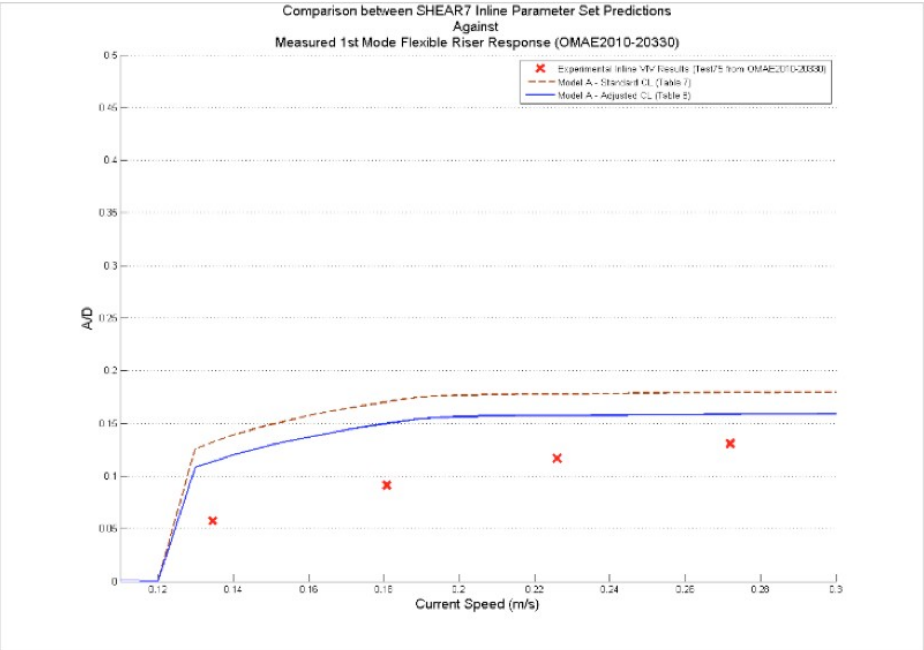

Figure 13: *Comparison between SHEAR7 using common.CL Tables 7 & 8 and the Test 75 Series Experimental Results A/D vs Current Velocity*

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 .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 H1 below shows a plot of A* versus c* for dozens of different risers modelled 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.

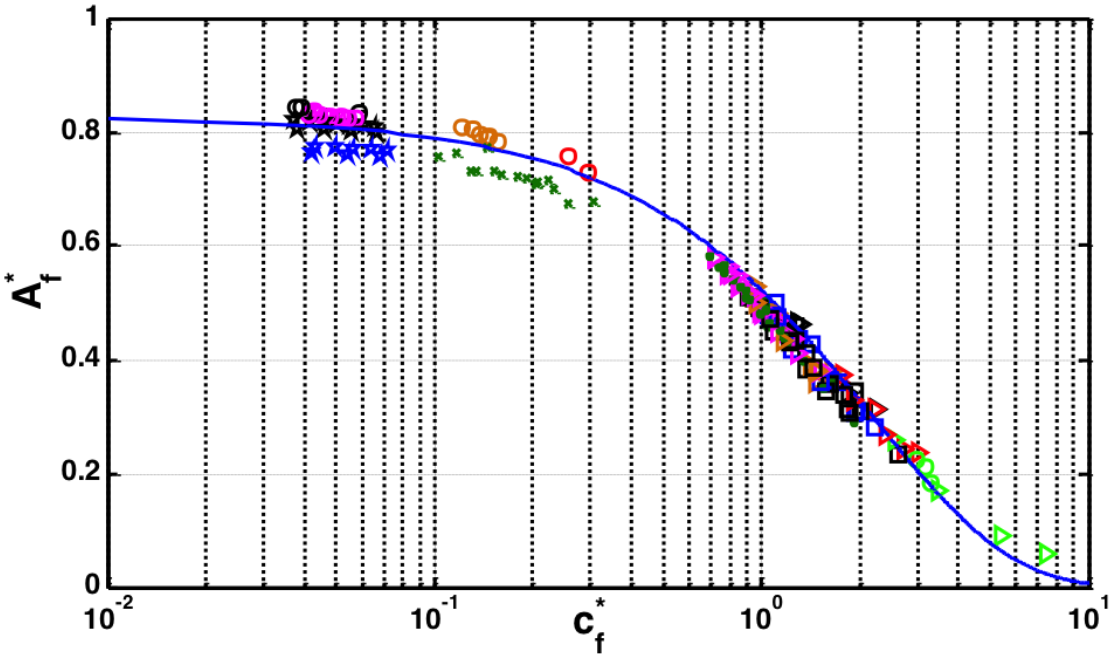

Figure H1: A* versus c* for a wide range of top tension, SCR and lazy wave risers with and without strakes.

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 H2 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.

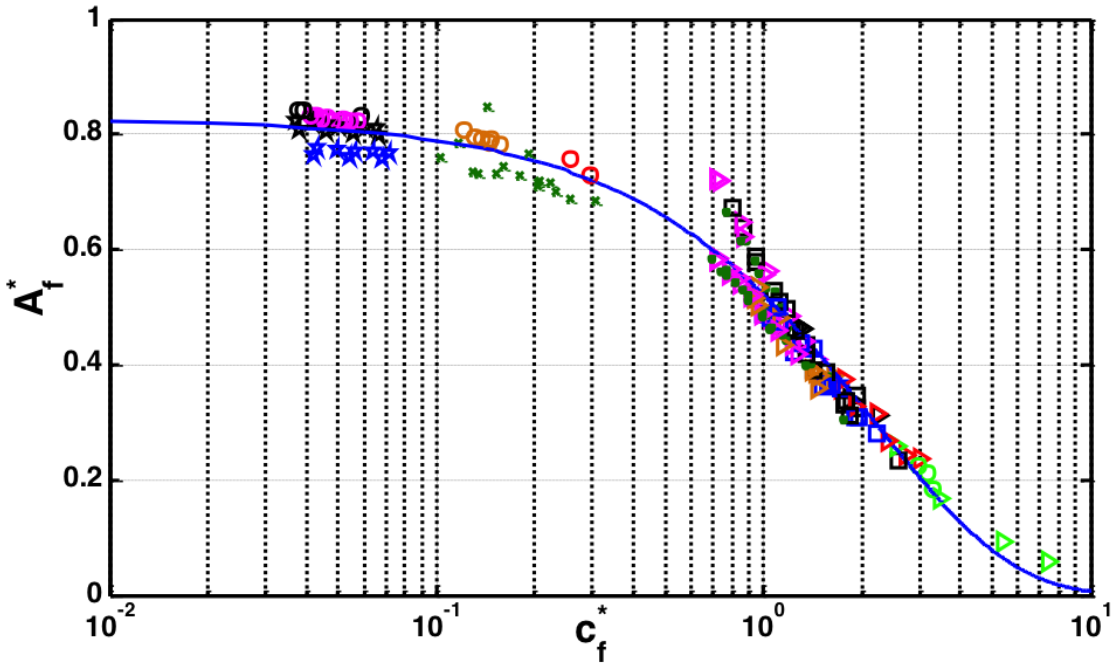

Figure H2: A^* versus c^* for a wide range of top tension, SCR and lazy wave risers with and without strakes. The branch on the top side of the curve revealed a program bug during development testing that was subsequently resolved prior to release.