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Load Transmission to Foundation of GBS – Dynamic Loading

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- When calculating the effects of dynamic or time varying ice loads applied to an offshore structure such as a bottom founded gravity base structure (GBS), it is of prime interest to know what percentage of the ice load applied at the waterline is transmitted to the foundation.
- The inertia and damping of the GBS will result in attenuation of the applied load and only some fraction of it may “reach” the foundation.

- The loads derived from the hull instrumentation on the Molikpaq in 1986 are generally larger than those obtained from the geotechnical information
- The question arises whether one of the instrumentation sets is in error or whether the load applied to the hull in the region of contact with the ice does not reach the foundation due to attenuation.

Models considered

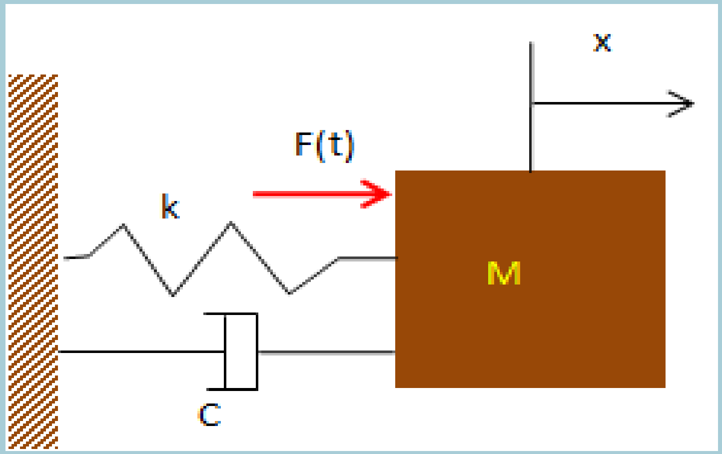

Figure 1 GBS with Spring Support and Damping – SDOF system

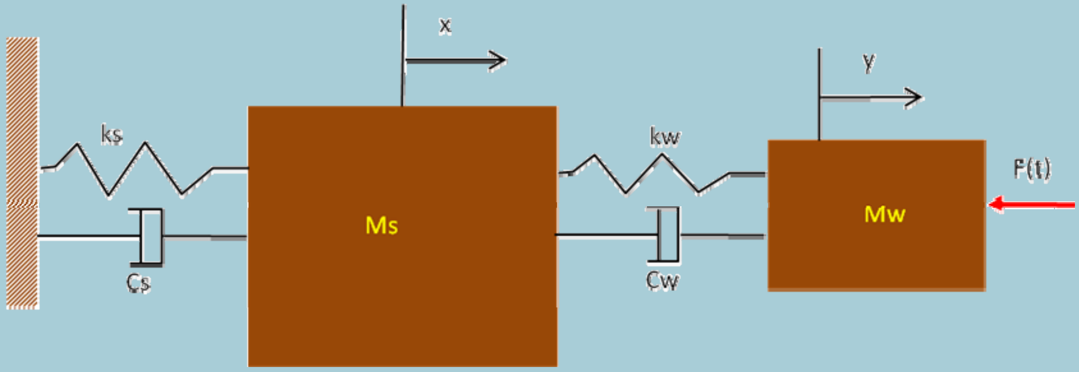

Figure 2 GBS with Wall – 2DOF system

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Model properties

Table 1 Model Properties						
	GBS Mass (tonnes)	Wall Mass (tonnes)	GBS Stiffness (kN/m)	Wall Stiffness (kN/m)	GBS Damping Ratio	Wall Damping Ratio
System 1 SDOF	289,208	N.A.	5×10^6	N.A.	0.25	N.A.
System 2 2DOF	289,208	7,500	5×10^6	9×10^6	0.25	0.05

GBS period = 1.5 s

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Model considerations

- The GBS stiffness and mass were determined from examination of past measurements and studies of the Molikpaq and SSDC
- The sand core mass and the three unloaded sides of the Molikpaq in the 2DOF model are considered to be a single mass moving in unison
- The stiffness of the loaded wall was determined considering the wall to be a beam supported at both ends and having an elastic foundation, i.e. the sand fill
- Since the sand fill was loose, the subgrade modulus of the beam afforded by the sand was taken as an appropriately low value

Mass summary

Table 2 Breakout of GBS mass				
Steel hull mass	Ballast water mass	Core fill mass	Added mass	Total
(tonnes)	(tonnes)	(tonnes	(tonnes)	(tonnes)
26,000	53,868	179,340	30,000	289,208

Response to standard sinusoidal load

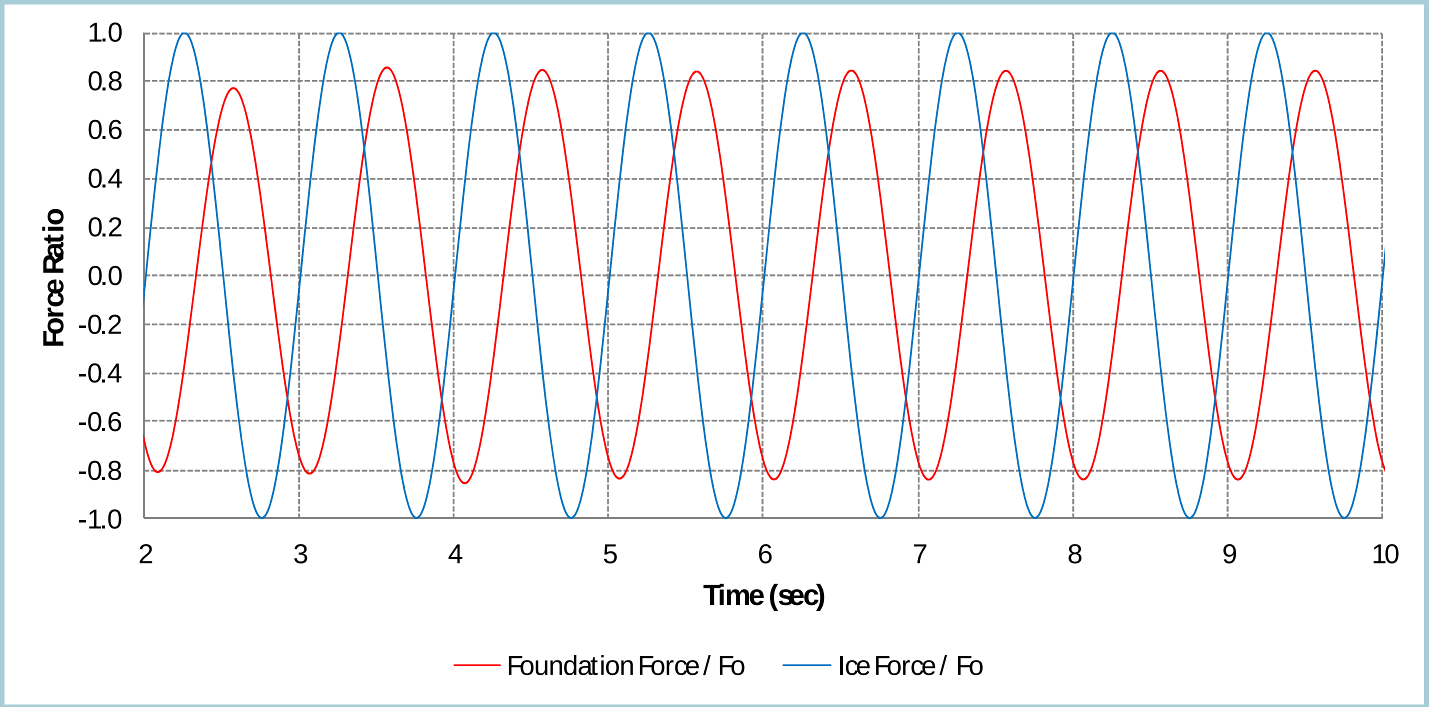

Figure 3 Simple sinusoidal loading of SDOF GBS (Molikpaq)

The ratio of maximum foundation load to applied load for this SDOF model is 0.84, the same as obtained from standard textbook equations

Ice load characteristics

- Loading experienced during ice events is different than this idealized example
- The load does not go negative but it usually goes from maximum to about 50 percent of maximum during a cycle
- The period of each cycle usually varies
- The maximum load reached is not a constant but it also varies
- The shape of the load/unload curve in time is not sinusoidal but is sawtooth in shape.

Load signature assumptions

- The period of the ice load was assumed to vary randomly between 0.9 and 1.1 seconds.
- The ramp-up was assumed to be constant at 0.8 times the period.
- The maximum load reached in each cycle was considered to vary between 0.85 and 1 times the maximum specified load, F_o, during a cycle
- The amplitude of each cycle was taken as 0.6 times the maximum cycle load.

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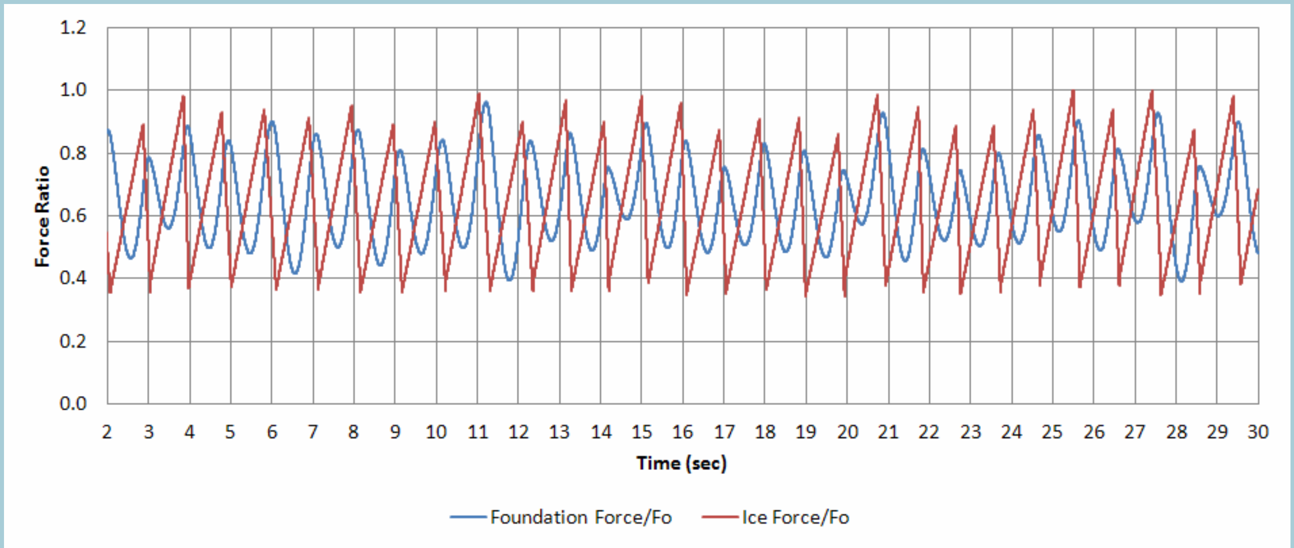
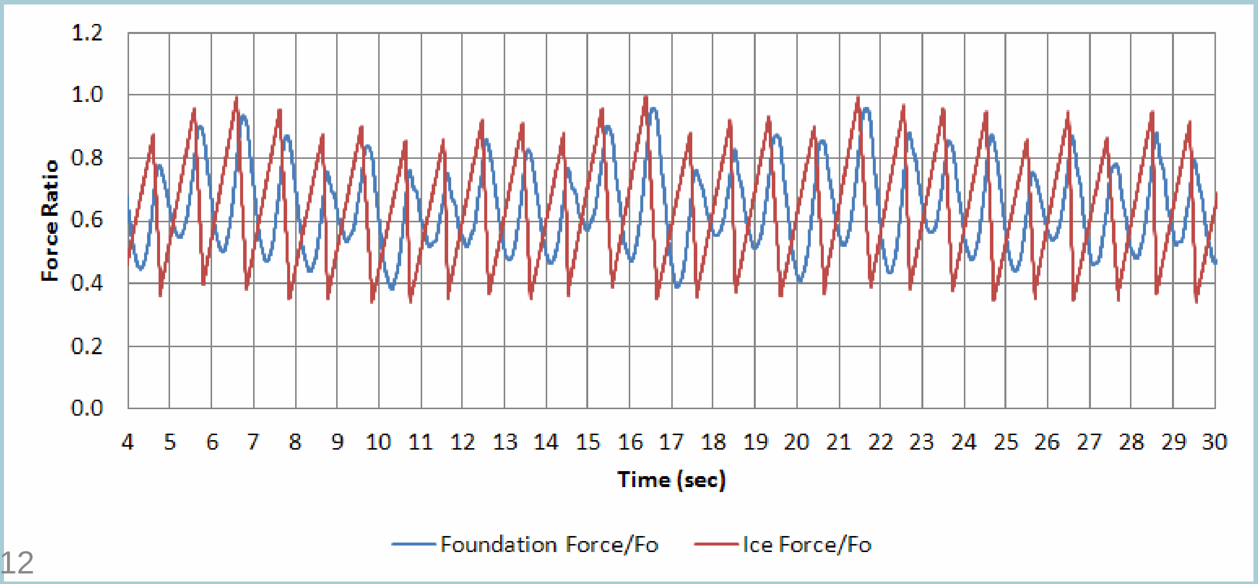
Resulting load vs. time traces

SDOF results



2 DOF results



Resulting force ratios

Table 3 Parametric analysis results					
GBS Foundation Stiffness k (kN/m)	GBS Damping ratio x	Maximum Force Ratio SDOF	Mean Force Ratio SDOF	Maximum Force Ratio 2DOF	Mean Force Ratio 2DOF
2.5E+06	0.15	0.89	0.72	1.00	0.76
	0.2	0.87	0.72	1.00	0.77
	0.25	0.87	0.73	0.98	0.78
5.0E+06	0.15	0.98	0.82	1.10	0.88
	0.2	0.95	0.90	1.09	0.88
	0.25	0.97	0.83	1.08	0.90
7.5E+06	0.15	1.22	1.0	1.34	1.08
	0.2	1.15	0.99	1.31	1.08
	0.25	1.11	0.97	1.26	1.06

Tuned and non-random

- Sawtooth forcing functions with constant period
- Tuned to the GBS natural period or a multiple of this period

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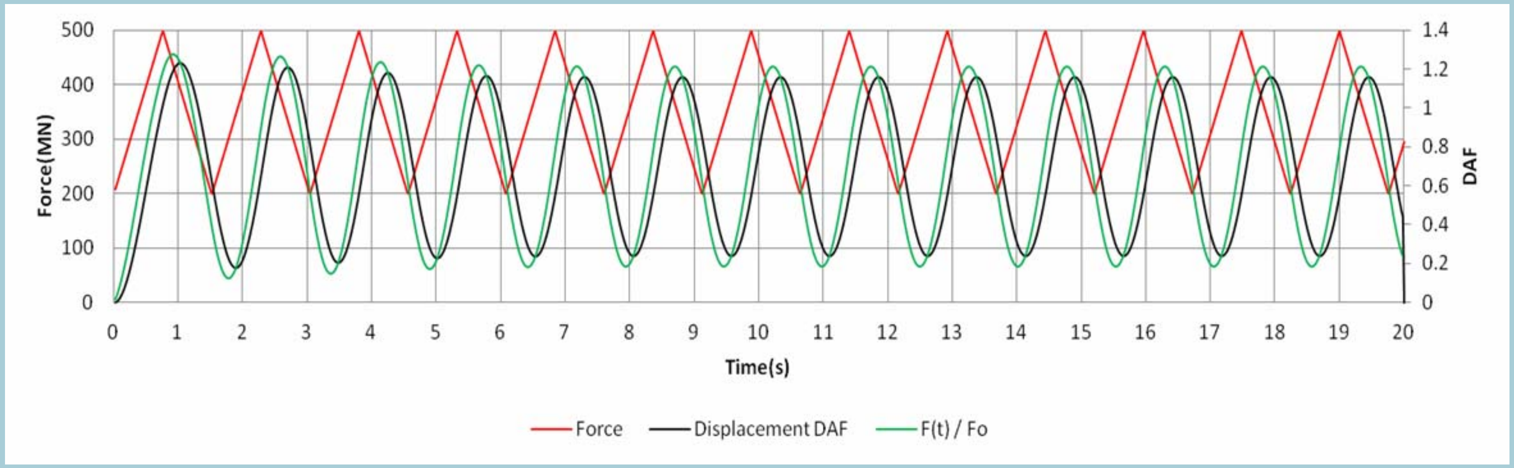
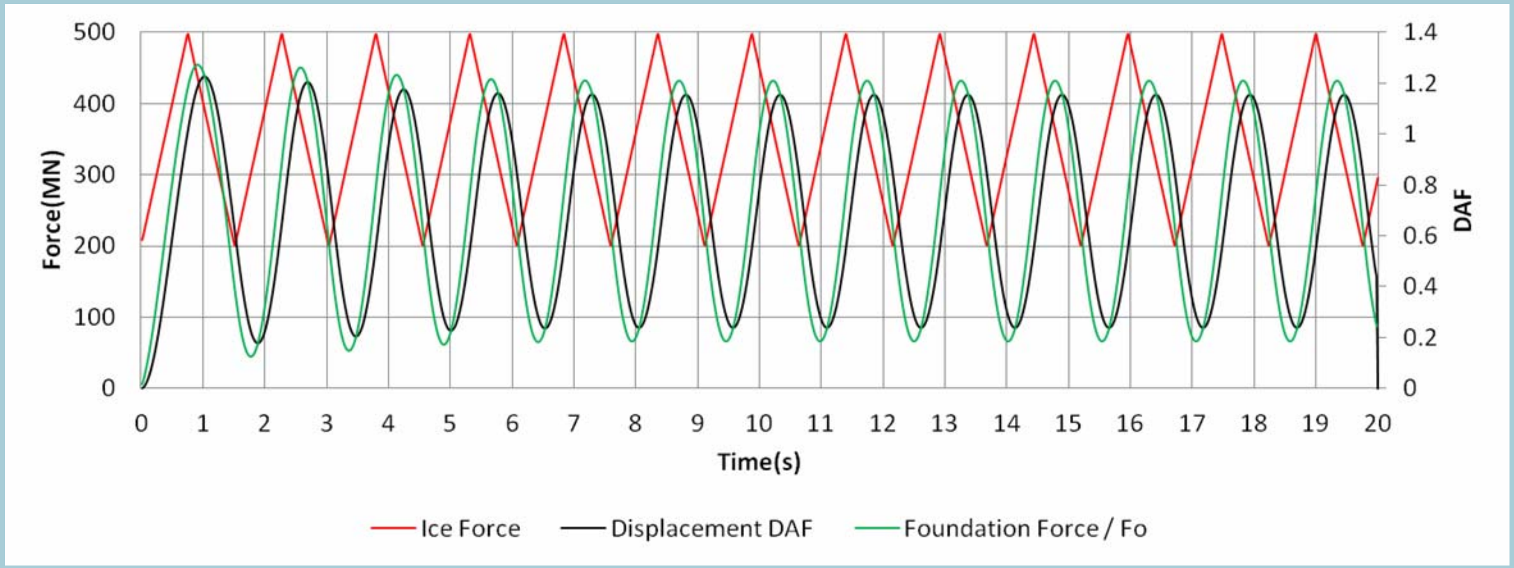
Force period / GBS period = 1

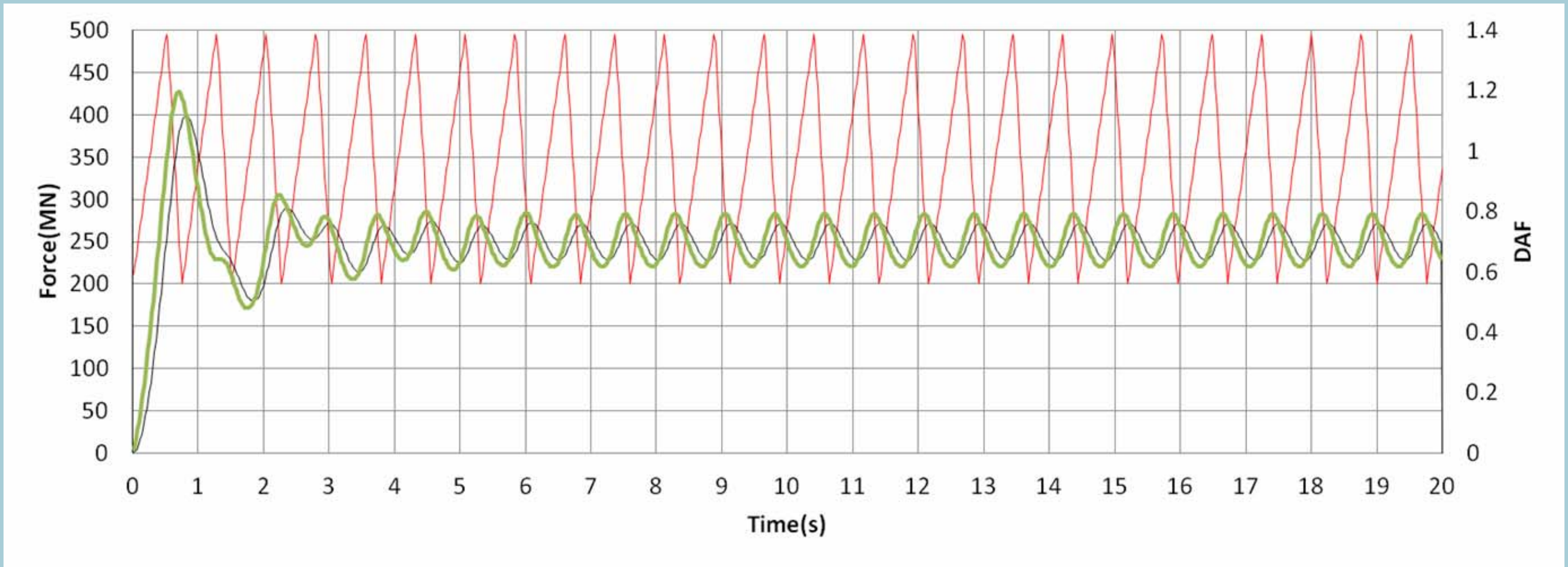
Ramp time = 0.5 Period



Ramp time = 0.7 Period



Force period / GBS period = 0.5



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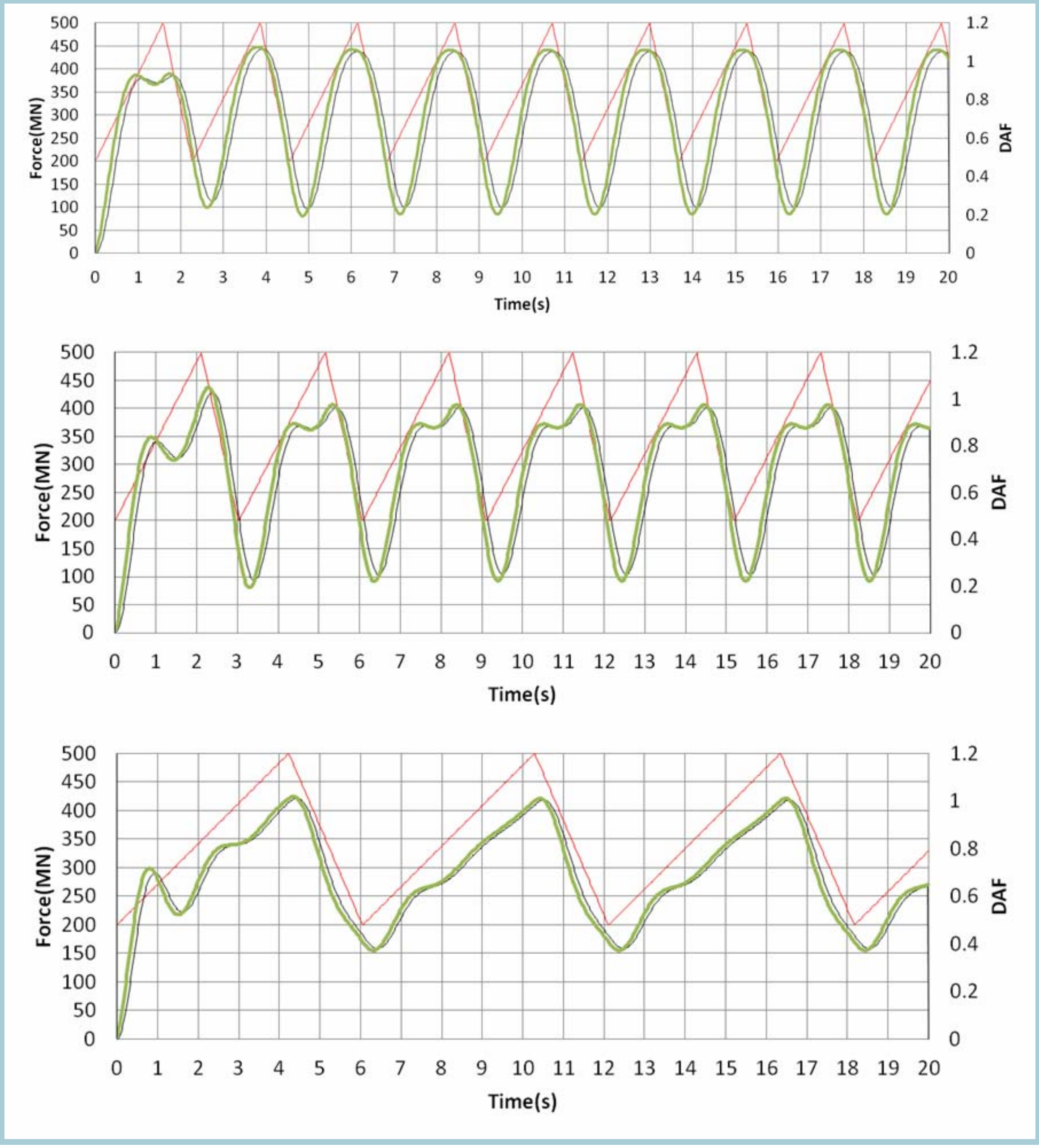
Force period =
1.5 GBS Period

Force period =
2 GBS Period

Force period =
4 GBS Period



Conclusions

1. Simple sinusoidal models are not adequate to determine the transfer ratios because of the much more complex nature of real ice loading vs. time behaviour.
2. The time varying ice load must be modeled to include the behaviour observed during loading events in the field. This entails providing a sawtooth load vs. time function with a constantly varying period and amplitude.
3. Stiffnesses and damping ratios are determined from measurements taken on large structures such as the Molikpaq and SSDC.
4. The proportion of applied ice load reaching the foundation depends mainly on the stiffness of the GBS and less so on its damping ratio.

Conclusions (cont'd)

5. Average ratios of foundation force to ice load vary from about 0.73 for SDOF and 2DOF systems at lower stiffness to about 0.85 at expected stiffness to 1 or greater than 1 at high stiffness.
6. For tuned forcing
   - the foundation force is 1.2 times the applied force if the frequency ratio is 1.0
   - the foundation force is ~0.7 of the ice force if the forcing period is 0.5 times the GBS period
   - the foundation force is ~1.0 times the applied force if the forcing period is a multiple of 1.5, 2, 3 or 4 of the GBS period
7. Stiffer structures will experience greater transfer ratios, with the ratios exceeding one at the highest stiffnesses.
8. The single degree of freedom system, which is more representative of planned offshore GBS structures, results in lower transfer ratios than the two degree of freedom system which models more closely a structure such as the Molikpaq.