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Incorporating magneto-Rheological damper into riser tensioner system to restrict riser stroke in moderate-size semisubmersibles

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Abstract. In case of conventional shallow-draft semisubmersibles, unacceptably large riser stroke was the restricting factor for dry-tree-riser-semisubmersible development. Many attempts to address this issue have focused on using larger draft and size with extra heave-damping plates, which results in a huge cost increase. The objective of this paper is to investigate an alternative solution by improving riser systems through the implementation of a magneto-rheological damper (MR Damper) so that it can be used with moderate-size/draft semisubmersibles. In this regard, MR-damper riser systems and connections are numerically modeled so that they can couple with hull-mooring time-domain simulations. The simulation results show that the moderate-size semisubmersible with MR damper system can be used with conventional dry-tree pneumatic tensioners by effectively reducing stroke-distance even in the most severe (1000-yr) storm environments. Furthermore, the damping level of the MR damper can be controlled to best fit target cases by changing input electric currents. The reduction in stroke allows smaller topside deck spacing, which in turn leads to smaller deck and hull. As the penalty of reducing riser stroke by MR damper, the force on the MR-damper can significantly be increased, which requires applying optimal electric currents.

Keywords: semisubmersible; dry-tree unit; TTR (top-tensioned riser); MR (magneto-rheological) damper; pneumatic tensioner; riser-stroke limit; active control; deepwater

1. Introduction

Dry-tree solution is an attractive option for offshore industry because of its easier and cheaper well-maintenance than the wet-tree development (Muehlner and Banumurthy 2015). This is possible by its ability for direct-vertical access of the well from the surface (Muehlner and Banumurthy 2015). However, in deepwater, dry-tree option faces several restrictions. The TTR (top-tensioned riser), which is typical for dry-tree development, can only be deployed for Spar and Tensioned-Leg Platform (TLP) due to their relatively small heave motions (Muehlner and Banumurthy 2015) (Sablok *et al*. 2011). However, spar platform has smaller deck spacing that limits payload, and TLP has water depth restriction (Muehlner and Banumurthy 2015). In addition

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to this, Spar and TLP are expensive and require complex offshore installation (Muehlner and Banumurthy 2015). These restrictions made dry-tree development for deepwater field very restrictive.

Semisubmersible can accommodate wider deck and can be deployed at any water depth (Muehlner and Banumurthy 2015). However, semisubmersibles typically have larger heave motions compared to TLP or spar (Chen *et al*. 2007). Large heave motions mean unacceptably large riser strokes, which makes semisubmersible a less-friendly option for dry-tree development (Muehlner and Banumurthy 2015). Industry has proposed low-heave semisubmersibles as a solution for dry-tree development (Muehlner and Banumurthy 2015). Most of the low-heave semisubmersibles have deep draft columns, which leads to a complex topside integration process with the hull since most quayside installations cannot accommodate deep-draft hull leaving industry with only offshore integration option (Muehlner and Banumurthy 2015). In the present study, we adopted a semisubmersible design whose draft is not so deep but can have reasonably small heave motions by considering cancellations of heave wave forces among columns and pontoons. The current stroke-limit of conventional hydro-pneumatic riser system used for TTR is around 25-30 feet.

Another solution to mitigate large heave motions in conventional semisubmersibles is to introduce damper into riser system. Dampers can reduce the relative motions between surface floater and its riser system. It has been used in building structures to suppress vibration from earthquake. Another example of its application is car suspension system (Bitaraf *et al*. 2009, Yang *et al.* 2013). A semi-active damper utilizing magneto-rheological fluid has been applied for the previously mentioned purposes in the industry (Yang *et al.* 2013). This damper is known as Magneto-Rheological Damper (MR Damper). MR Damper has the ability to modify its damping coefficient by changing the energizing electric current (Kwok *et al*. 2006). This active-control ability provides an edge compared to the passive pneumatic-viscous damper. So far in offshore industry, the MR damper was used only for fixed jacket platforms to reduce dynamics caused by earthquakes or ice loadings.

During the past two decades, the researchers in the lab of the second author have developed fully coupled time-domain hull-mooring-riser simulation program for various applications. The capability of the computer program was recently extended to include MR damper between floaters and risers. The interface can also adopt control modules. The low-heave semisubmersible and MR Damper coupled simulation program can potentially provide a cost effective solution for dry-tree development. The riser stroke is reduced by having lower heave motion and controlled MR damper. The present generic low-heave semisubmersible is designed such that its draft is acceptable for quayside integration. The developed system is to have lower riser strokes compared to conventional semisubmersibles.

The main objective of this paper is to present the time-domain simulation results with linear dampers and MR Dampers in the riser system as means to reduce riser strokes to a manageable level so that it can allow smaller semisubmersibles for dry-tree development. This paper also illustrates how the semisubmersible parameters and damper characteristics can be utilized together for improved performance.

2. Magneto-rheological damper

MR Damper is a semi-active structural damper filled with magneto-rheological fluid (MR fluid), a type of fluid that exhibits viscoelastic behavior when subject to magnetic field (Wang and Liao 2011). The magnetic field is generated when applying electric current to the MR damper. The viscoelasticity of the MR fluid then determines the damping coefficient of the MR Damper. This means that the MR Damper damping coefficient can be adjusted by adjusting the electric current that induces the magnetic field (Kang *et al.* 2017). This results in a type of smart damper. Fig. 1 below shows a typical schematic of MR Damper.

The MR Damper system curve (force vs velocity) can be best represented numerically using Nonlinear Hysterectic Arctangent model (Yang *et al*. 2013). The force exerted by the MR Damper can be represented by the following equation:

$$F_{MR\ Damper} = c\dot{x} + kx + \alpha \tan^{-1}\left(\beta\dot{x} + \delta sgn(x)\right)$$

where c is the viscous damping coefficient of the MR Damper, k is the stiffness coefficient of the MR Damper, α is the hysteresis factor of the MR Damper, and β and δ are the arctangent factors of the MR Damper. x and $\dot{x}$ are riser stroke and riser-stroke velocity, respectively. Parameters c, k, α, β, and δ are determined from parametric studies, where the coefficients are determined to best-fit the physical MR Damper system curve

As can be seen from the plot below, the MR Damper system is not a conventional linear/viscous damping curve. It exhibits a hysteresis feature (the loop in the curve) which is represented by the arctangent function in the MR Damper equation above (Yang *et al*. 2013). The right plot in Fig. 2 shows an exemplary large-scale MR Damper system curve for various energizing currents. The large-scale MR Damper is the type that is numerically configured so that it can be used for offshore riser application. One can see that by applying different currents, the damping coefficient (the slope of the curve) can be modified according to the need. This demonstrates the advantage of the damper as opposed to the constant damping coefficient of linear/viscous damper. Note that the MR Damper system with energizing currents of 0.0A, 0.1A and 0.21A are used for this analysis (see Table 3).

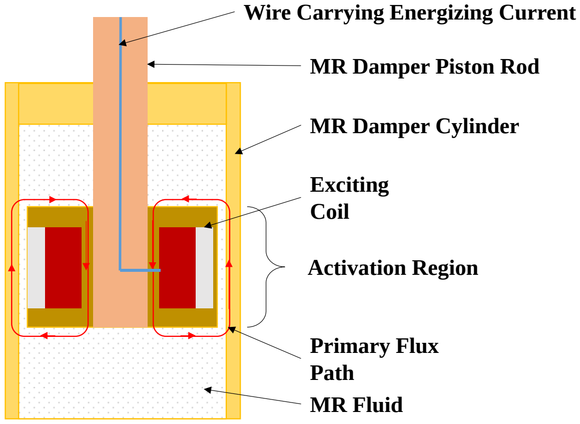

Fig. 1 Schematic and configuration of an MR damper

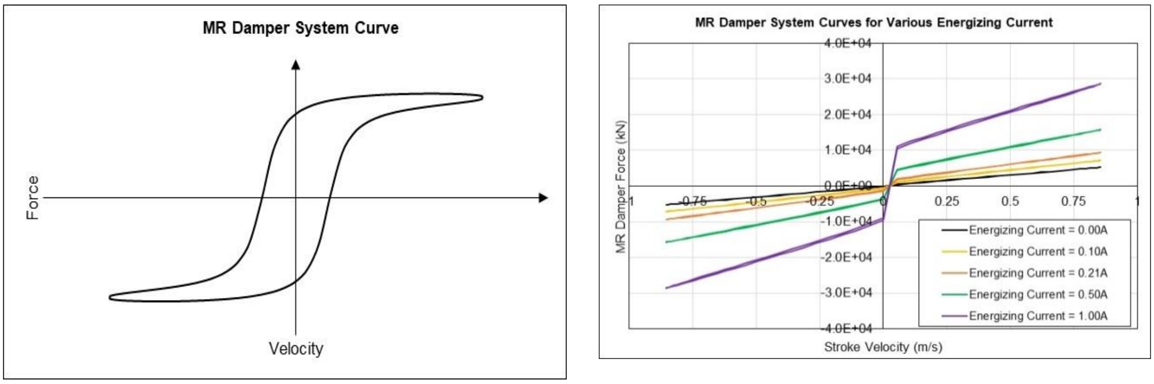

Fig. 2 Generic MR damper system curve (left) and scaled MR damper system damping curve for various energizing current (right)

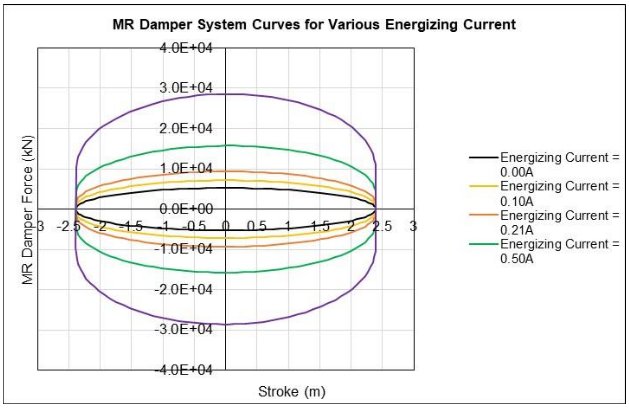

Fig. 3 MR damper stiffness (force versus stroke) curve for various energizing current

MR Damper also has another unique feature, which is stiffness component, albeit small compare to the damping part. The plot above shows MR Damper force vs stroke (or displacement). From the plot, one can see that the maximum force occurs at zero stroke. This is because at zero stroke, the stroke velocity is at its maximum, hence damping force is also at maximum. However at maximum stroke (or zero stroke velocity) the MR Damper force does not go to zero. This is due to the stiffness component of the MR Damper that generates a restoring force at maximum stroke.

3. Incorporation of damper into riser system

The MR damper is incorporated into a typical hydro-pneumatic riser system by attaching it at the top of the riser, similar to the riser tensioner system (see schematic below). In this configuration, the MR damper reacts to the riser stroke and riser stroke velocity, together with the riser tensioner system.

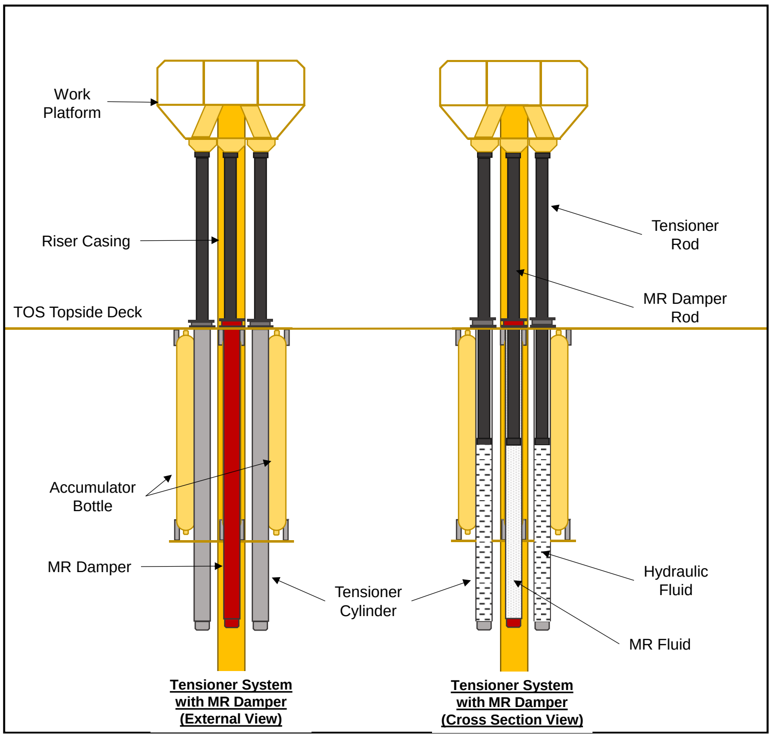

Fig. 4 Riser system top elevation view with tensioner and damper

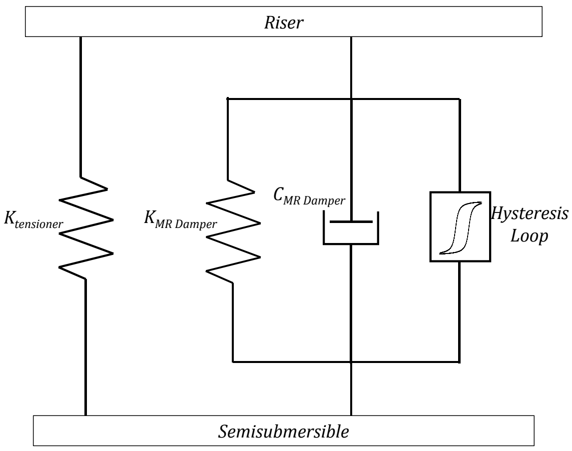

Fig. 5 A Free-body diagram of MR damper in riser tensioner system

The above free-body diagram represents the overall riser-tensioner and MR Damper system in the semisubmersible system:
For comparative analysis, the linear damping system is incorporated in the same manner as the MR Damper, except that it does not have the stiffness term and the hysteresis term.

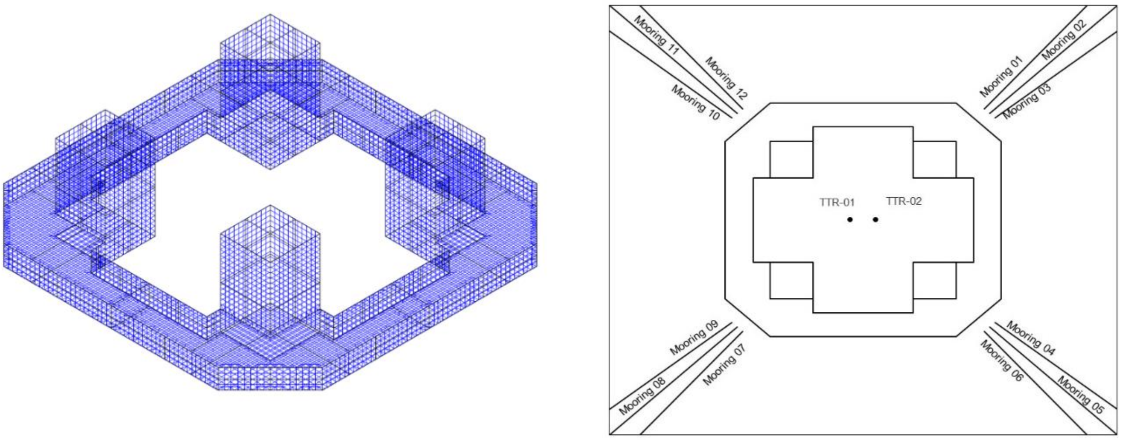

Fig. 6 Isometric view and top view of the semisubmersible

4. Hull-mooring-riser coupled analysis

The coupling of hull-mooring-riser analysis (Yang and Kim 2009, 2010, Kang and Kim 2014) was performed in two stages. The first stage is to run frequency-domain 3D diffraction/radiation panel program to obtain the frequency-dependent hydrodynamic coefficients. 9450 quadra-lateral panels were used to obtain hydrodynamic forces and coefficients with reasonably good accuracy. The coefficients are then used as inputs to fully-coupled hull-riser-mooring time-domain simulation program, Texas A&M in-house CHARM3D program. In CHARM3D, the nonlinear viscous drag forces of the semisubmersible pontoons and columns are calculated at the instantaneous position at each time step using Morison's equation. The nonlinear drag forces are also integrated up to the instantaneous free surfaces. The second-order mean wave drift forces were also calculated to simulate slowly varying wave drift motions in surge and pitch/roll by using Newman's approximation method. The details of all the hydrodynamic calculations are summarized in reference (Zainuddin2017).

The hull is shaped and sized according to (Muehlner and Banumurthy 2015). Fig. 6 shows the corresponding hull shape, mooring arrangement, and riser locations. The hull sizing was performed based on the requirement of having the draft to be within 30 m (~100 ft) so that its heave motions are acceptable without increasing the cost too much. The principal dimensions of the semisubmersible system are tabulated below:

For illustration, two top-tensioned risers are adopted, as shown in Fig. 6. 12 moorings lines are also modelled in the time-domain simulation. The hydro-pneumatic riser connection to the hull is based on a popular nonlinear numerical model (Kang *et al*. 2014, Kang *et al*. 2017, Yang *et al.* 2013). The hull-mooring-riser coupled dynamic simulation computer program for various floating platforms has been verified against many experimental and field data.

The risers are attached near the center well of the semisubmersible and the mooring lines are attached at the four corners of the hull. The table below summarizes the riser and mooring data.

The preliminary analyses of the required damper are performed in two stages. The first stage is to find the required damping coefficient to meet a stroke target. The second analysis is to configure MR Damper system curve to meet the required damping coefficient from the previous analysis.

The first analysis is performed by using linear damping configuration. Through a series of sensitivity analysis, a set of damping coefficients are implemented on the riser to achieve the required stroke. The result leads to a damping coefficient of 9000 kN/ms-1. Afterwards, the MR Damper is numerically configured to meet the required damping coefficient from the first analysis. This is done by applying energizing current of 0.21A to the MR Damper to achieve the required damping level (see section Magneto-Rheological Damper and Fig. 2). Note that the MR Damper can apply smaller or larger damping coefficients by applying smaller or larger currents, respectively, depending on need. The semi-active feature of MR Damper with control is not investigated in the present study. The table below summarizes the damper parameters.

As for design ocean environments, Gulf of Mexico (GoM) 1000-Hurricane storm is used in the present time domain simulation to analyze the performance of the respective dampers to suppress riser strokes in the most severe sea environment.

Table 1 Semisubmersible principal dimensions

Parameter	**Mid-Case**
Water Depth	1219.2 m (4000 ft)
Draft	28.96 m (95.02 ft)
Column Spacing	56.39 m (185 ft)
Column (Length x Width)	17.0 m x 17.0 m (55.78 ft x 55.78 ft)
Pontoon Width	13.00 m (42.65 ft)
Pontoon Height	6.72 m (22.05 ft)
Pontoon Length	108.81 m (357 ft)
Waterplane Area	1156.00 m^2 (12,444 ft^2)
Submerged Volume	67,644 m^3 (2,389,159 ft^3)

Table 2 Semisubmersible riser and mooring line

Parameters	**Value**
No of Mooring Lines	12
Pretension per Mooring Line	2,030 kN (456.36 kip)
Mooring Line Length	2,031.80 m (6,666.32 ft)
No of Riser	2
Pretension per Riser	4928.60 kN (1108.00 kip)
Riser Tensioner Nominal Stiffness	492.86 kN/m (33.77 kip/ft)

Table 3 Riser dampers' details

Parameters	**Linear/Viscous Damper**	**MR Damper (energizing current 0.0A)**	**MR Damper (energizing current 0.1A)**	**MR Damper (energizing current 0.21A)**
No of Riser Equipped with Damper	2	2	2	2
Damping Coefficient (c)	9,000 kN/ms^{-1} (617 kip/fts^{-1})	6,000 kN/ms^{-1} (410 kip/fts^{-1})	7,449 kN/ms^{-1} (510 kip/fts^{-1})	9,061 kN/ms^{-1} (621 kip/fts^{-1})
Stiffness Coefficient (k)	N/A	9.8 kN/m (0.67 kip/ft)	21.8 kN/m (1.5 kip/ft)	35 kN/m (2.40 kip/ft)
Hysteresis Coefficient (α)	N/A	8 kN (17.99 kip)	516.7 kN (116.16 kip)	1,057 kN (237.51 kip)
Arctangent β Coefficient	N/A	17.82 s/m (5.43 s/ft)	20.03 s/m (6.10 s/ft)	22.45 s/m (6.84 s/ft)
Arctangent δ Coefficient	N/A	2.3	2.6	3

Current design guidelines require offshore industry to do survivability check for this kind of environment. Therefore, the justification of using 1000-H storm is that the MR damper is to suppress the riser stroke in the survival mode to avoid riser-system damage. Serious damage may happen when riser stroke exceeds its stroke limit. The table below summarizes the metocean condition. It is assumed that the winds-waves-currents are collinear and incident from the x/surge direction.

Table 4 Gulf of Mexico (GoM) 1000-H metocean condition (American Petroleum Institute 2007)

Parameters		**1000-H**
Significant Wave Height		19.8 m (64.7 ft)
Peak Period		17.2 s
Overshooting Parameter, γ		2.4
Main Direction of Waves		180 deg
Direction of Current		180 deg
Current Profile	Surface Speed	3 m/s (9.8 ft/s)
	Speed at Mid-Profile	2.25 m/s (7.4 ft/s)
	Zero-speed Depth	126 m (413.4 ft)
Wind Speed	10 m Elevation (1 hour speed)	60 m/s (196.9 ft/s)

5. Results and discussions

Fig. 7 below shows the 100-yr and 1000-yr input wave amplitude spectra and the heave RAO (solid line) for the free-floating semi-submersible from frequency-domain potential-based linear hydrodynamic analysis. The two other RAOs are for with TTR+linear-viscous damper and with TTR+MR damper. The heave natural period of the free-floating case is located outside the GoM 100-yr and 1000-yr significant-wave-energy ranges, which results in favorable heave motions. It allows lower riser strokes compare to conventional semisubmersibles. The two heave RAOs with TTR+dampers were regenerated from the corresponding time histories obtained from time-domain simulations. Note that for both cases with TTR+dampers, the amplitudes of heave RAOs become smaller than that of potential-based free-floating case especially near the peak of input wave spectra i.e. the cancellation period becomes closer to the peak of input spectra. On the other hand, the heave natural period also becomes closer to the input wave spectra although the heave resonance peak is greatly reduced, so there is no serious negative effect. With additional dampers, the resonance peaks can further be lowered. The statiscal details of the heave motions are tabulated in Table 6. Many designers try to locate the local minimum (so-called waveless region or cancellation period) near the spectral peaks to minimize the heave motion in the stage of frequency-domain-RAO analysis. To authors' point of view, this is not a good strategy since the heave RAO increases very rapidly after the local minimum and its pattern can change after including viscous effects and TTRs, as demonstrated in Fig. 7. Due to the expected low heave motions even in the 1000-yr hurricane, the current semisubmersible hull shape without using large draft, has a potential to be used with dry-tree TTR riser system. The reduced heave motions result from the compensation of heave wave forces between column-bottoms and pontoons. The further reduction of the riser stroke can be done by additionally employing MR damper system, which can only be activated when necessary, emergency situation.

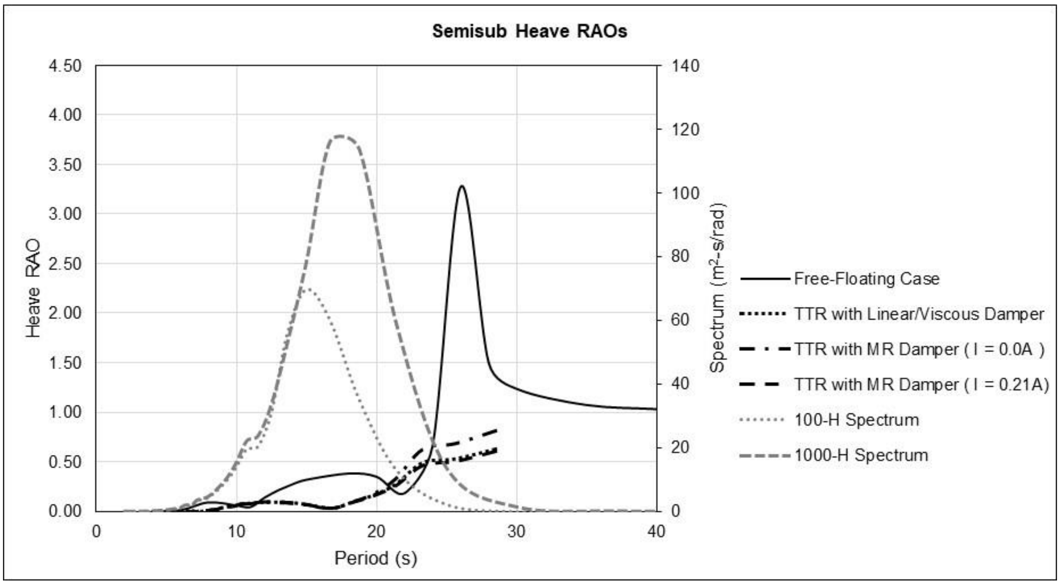

Fig. 7 Input wave spectra and heave RAOs for free-floating and with TTR+dampers cases

The total riser stroke (without damper implementation) for the aforementioned semisubmersible is 7.55 m (24.76ft), which is lower than conventional semisubmersible (Muehlner and Banumurthy 2015). The improvement of the riser stroke sets a propitious precedent for further stroke reduction by employing additional dampers. Through the implementation of the linear damper as discussed above, the riser stroke is further reduced to 3.60 m (11.80ft). The implementation of comparable MR Damper with energizing current of 0.21A results in total stroke of 3.83 m (12.58ft). The table below summarizes the riser stroke. Therefore, by employing additional dampers, the riser strokes are reduced by half. The linear-damper case is only theoretical and 100% passive system, so there is no room of control or minimizing wear-and-tear. In contrast, the MR damper can only be employed when necessary, so there is no wear-and-tear problem.

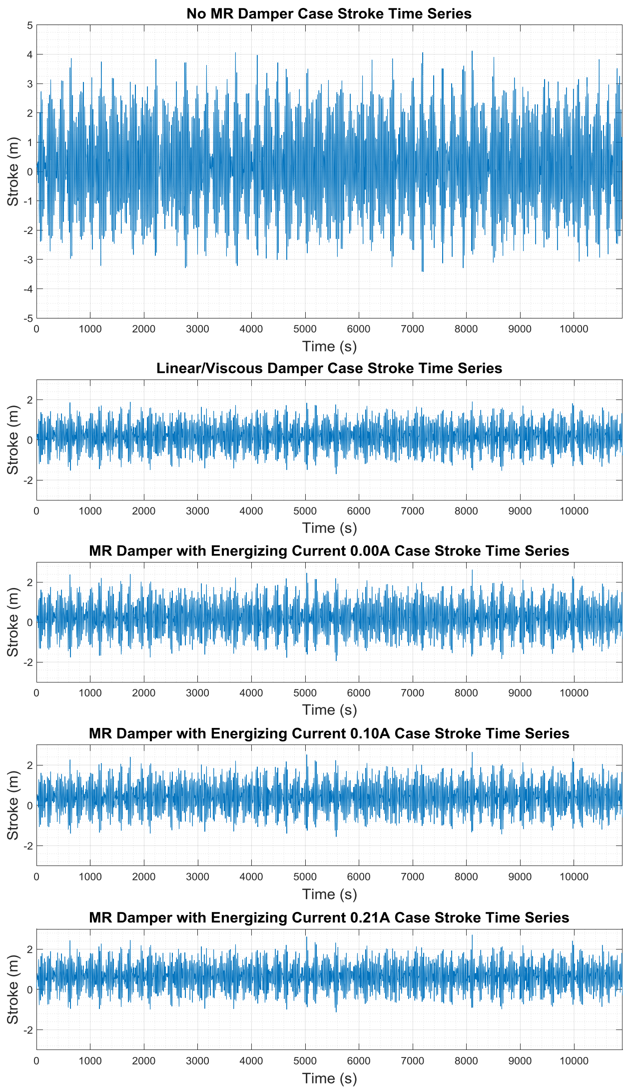

Fig. 8 Riser-stroke (TTR2) time histories for various cases

Table 5 Riser stroke (TTR-2) with and without the application of dampers

Parameters		Without Damper	Linear Damper	MR Damper (I=0.00A)	MR Damper (I=0.10A)	MR Damper (I=0.21A)
Riser Stroke	Max Upstroke	4.12 m (13.50 ft)	1.90 m (6.22 ft)	3.62 m (8.59 ft)	2.64 m (8.66 ft)	2.71 m (8.89 ft)
	Max Down stroke	3.43 m (11.26 ft)	1.70 m (5.58 ft)	1.94 m (6.38 ft)	1.56 m (5.11ft)	1.13 m (3.69 ft)
	Total stroke	7.55 m (24.76 ft)	3.60 m (11.80 ft)	4.56 m (14.97 ft)	4.20 m (13.77 ft)	3.83 m (12.58 ft)

Riser-stroke time series for the cases with and without dampers are shown in the plots above (Fig. 8). From the time series plot, one can clearly see that the introduction of damper (linear and MR) significantly reduces the riser-stroke peaks leading to reduction of maximum stroke. One can also see that the stroke peaks are inversely proportional to the applied energizing current of MR Damper (or the corresponding damping coefficients of MR Damper). This means that one can modify the MR- damper damping coefficient to proper level to meet certain stroke requirements or achieve certain desired output.

The reduction of riser stroke indicates the dissipation of energy in the semisubmersible-riser system as a result of applied additional damping. This dissipation can also be illustrated in the riser stroke energy spectrum as below (see Fig. 9). Those riser-stroke spectra are generated from the above time series. The riser-stroke spectral peak for without-damper case is much higher than that with the damper. With increasing electric current in the MR damper, the stroke level gets reduced.

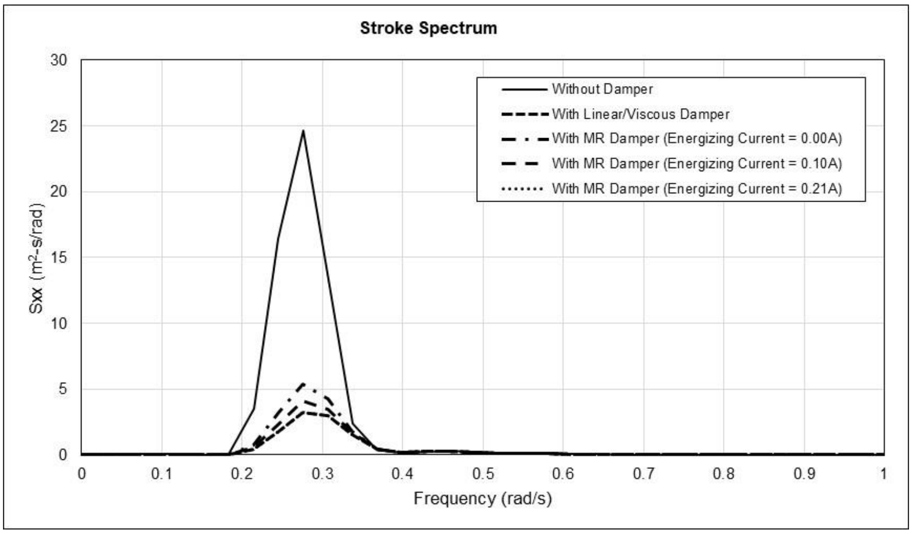

Fig. 9 Riser-stroke (TTR2) spectra

The introduction of dampers also causes significant reduction in the semisubmersible heave motion. Table 6 below summarizes the semi-submersible heave motions for the cases with and without dampers. The total heave motion range without-damper is 7.91 m (25.93 ft), while with dampers on riser, the total heave range is reduced to 4.18 m ~ 5.16 m. The corresponding reductions of heave time series and spectra by adding riser dampers are shown in Figs. 10 and 11.

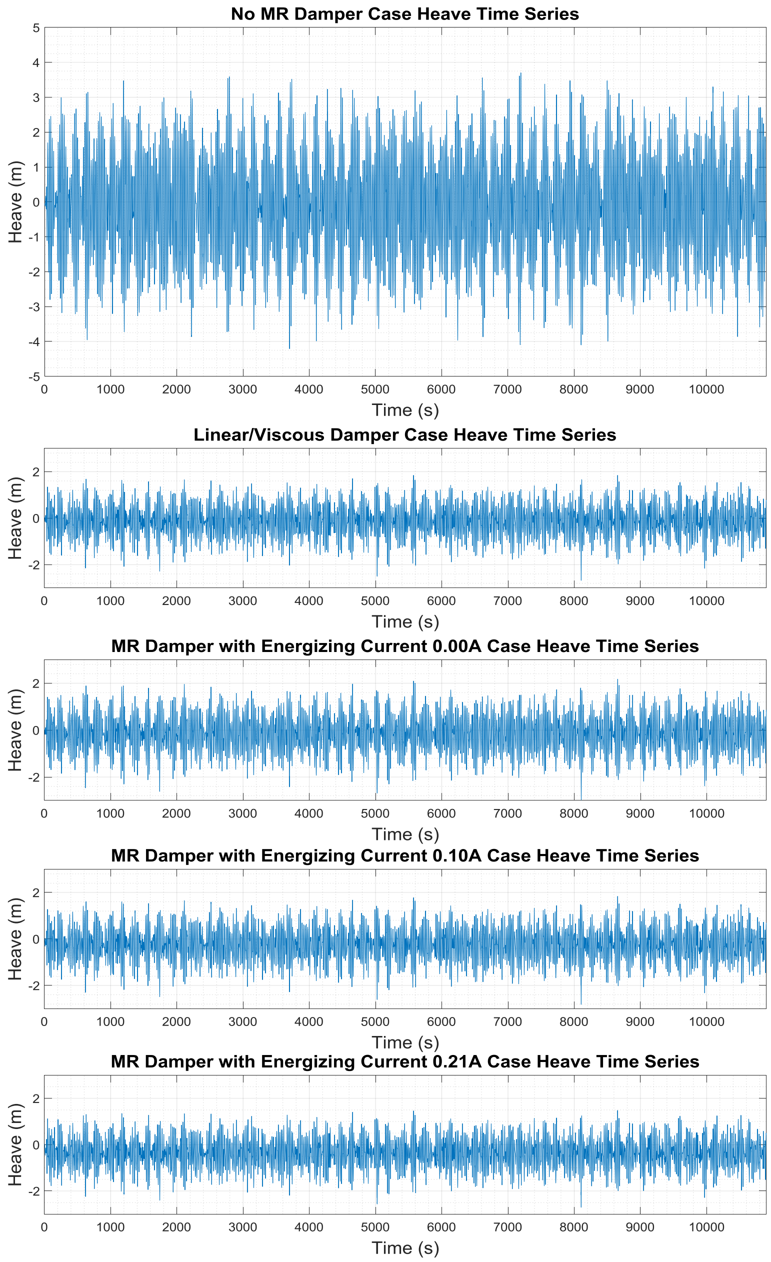

Fig. 10 Platform heave time histories for various cases

Table 6 Heave motion of the semisubmersible (with and without damper)

Parameters	**Without Damper**	**Linear Damper**	**MR Damper (I=0.00A)**	**MR Damper (I=0.10A)**	**MR Damper (I=0.21A)**
Max Upward Heave (m)	3.70 m (12.14 ft)	1.84 m (6.05 ft)	2.18 m (7.14 ft)	1.83 m (6.02 ft)	1.48 m (4.86 ft)
Max Downward Heave (m)	4.21 m (13.81 ft)	2.68 m (8.80 ft)	2.98 m (9.78 ft)	2.82 m (9.25 ft)	2.70 m (8.87 ft)
Total Heave Motion (m)	7.91 m (25.95 ft)	4.52 m (14.85 ft)	5.16 m (16.92 ft)	4.65 m (15.27 ft)	4.18 m (13.73 ft)

It is clearly seen that the introduction of damper (linear or MR) reduces the heave peak values to lower level too. This shows that the damper-induced suppression of riser stroke is strongly coupled with the suppression of semisubmersible heave motion. This also indicates that stroke motion is heavily dependent on platform heave motion such that any effort to reduce stroke should concentrate on reducing the platform heave motion.

The reduction of heave motion in damper cases is due to the dissipation of energy in semisubmersible-riser system. This is also illustrated in the heave spectra, as below (Fig. 11). The reduction is effective in the range of 0.15 rad/s ~ 0.4 rad/s. For higher frequencies than that, the presence of MR Damper does not affect the heave motion. It is understandable considering that the high-frequency range is dominated by inertia forces and not by damping/stiffness forces. Fig. 12 shows that there is close correlation between the platform heave motion and riser stroke.

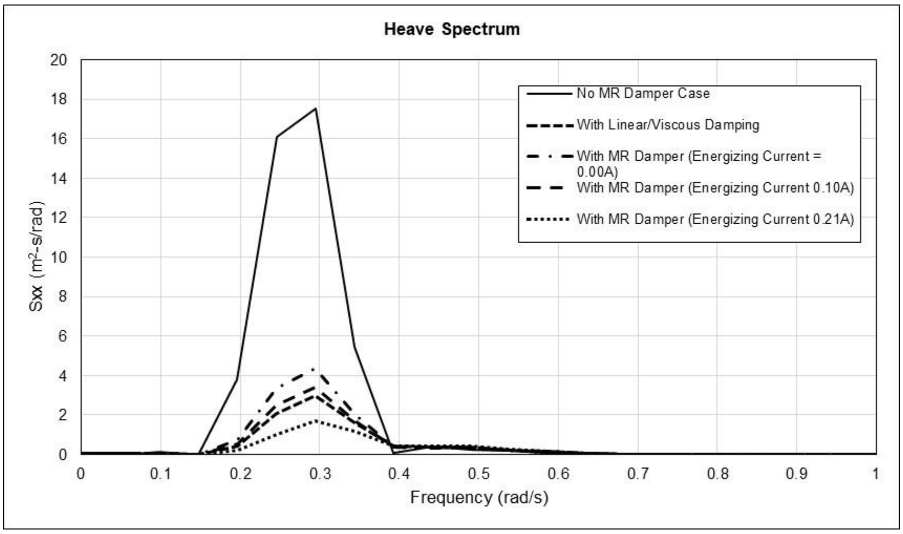

Fig. 11 Semisubmersible heave spectra (with and without damper)

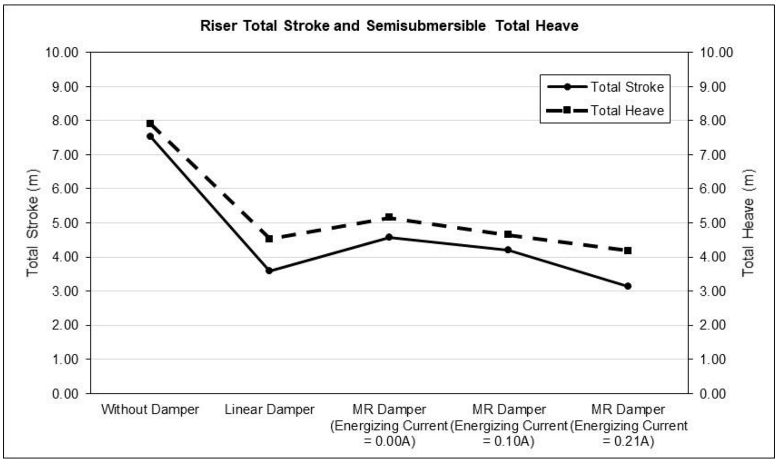

Fig. 12 Riser total stroke (TTR2) and semisubmersible total heave

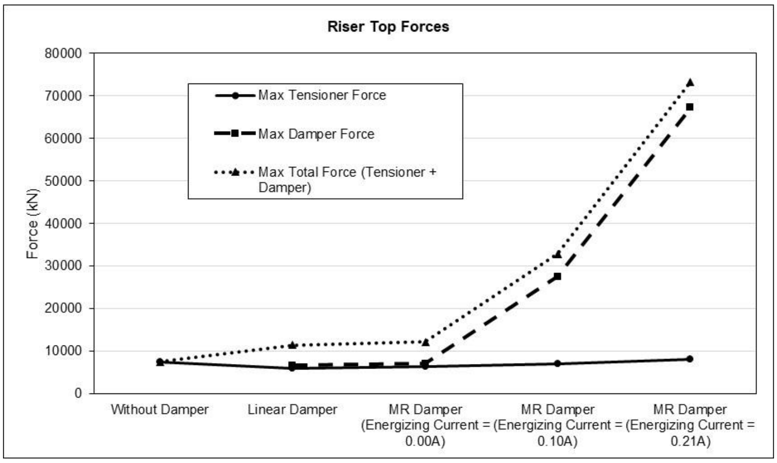

Fig. 13 Riser-top forces (Tensioner w/wo dampers)

When semisubmersible heave motions are large, the corresponding riser stroke can be beyond the allowable stroke distance, which results in repeated impact loadings and the corresponding damage of the system. This can be avoided by turning on additional MR damper, as demonstrated in the given example. The damping level can be controlled by controlling input electric current so that the riser system can barely avoid the risk. However, the benefit of having lower stroke comes at the price of having larger overall riser force. The damper introduces new force into the system (called the damper force or MR Damper force). The plot below (Fig. 13) illustrates the maximum damper force, the maximum tensioner force, and the maximum riser-top total force. Nevertheless, the force increased by dampers is still smaller than that by repeated impact loadings by piston on the bottom of riser cylinder when stroke is not diminished. As conclusion, the optimal electric current without increasing the riser total force too much while avoiding slamming on riser cylinder bottom by piston can be figured out and supplied.

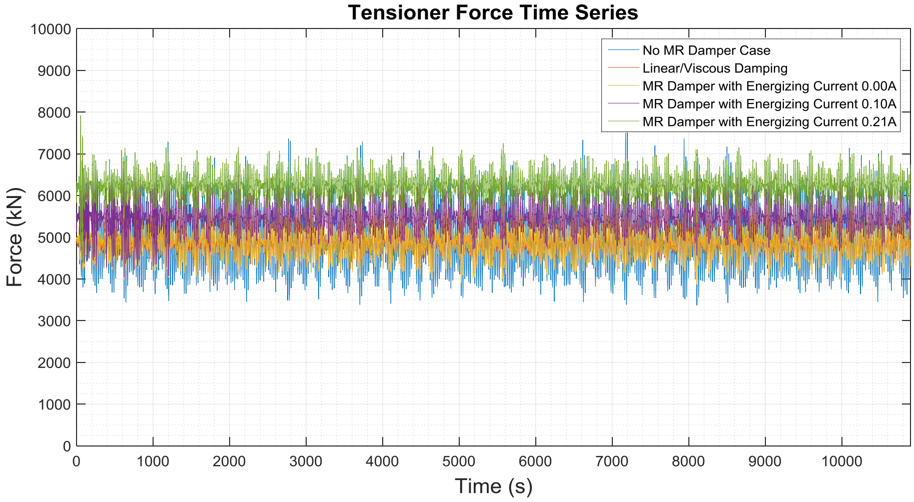

Fig. 14 Tensioner-top-force time series for various cases (TTR 2)

Table 7 Variation of mooring top-tensions (with and without damper)

Parameters	Without Damper		Linear Damper		MR Damper (I=0.00A)		MR Damper (I=0.10A)		MR Damper (I=0.21A)	
	Magnitude (kN)	Leg No.	Magnitude (kN)	Leg No.	Magnitude (kN)	Leg No.	Magnitude (kN)	Leg No.	Magnitude (kN)	Leg No.
Maximum Top Tension	4549.631	4	4452.75	4	4472.668	4	4448.27	4	4390.917	4
Minimum Top Tension	1106.19	9	1200.908	9	1194.035	9	1196.652	9	1196.176	9

One interesting phenomenon with MR Damper is the amplification of the MR Damper force with increasing electric current. In these cases, the hysteresis component of the MR Damper exerts a significance influence to the system, leading to the amplification of stroke velocity which then leads to the amplification of damping force. The present model is for only two TTRs. Typically, there are more than two risers in practice, and thus the increased riser forces will be more evenly shared among many TTRs. Therefore, the rate of force increase is to be less steep in such a case. The plots above (Fig. 14) show the pneumatic-riser-tensioner-force time series for the cases with and without dampers. After adding extra MR dampers, its mean tensions are increased with increasing electric current but dynamic tensions are decreased to keep them similar, as shown in Figs. 13 and 14. It means that there is no need of modification for the pneumatic tensioner.

The maximum total riser force is higher for both Linear-Damper and MR-Damper cases, compared to Without-Damper case. The MR Damper can significantly increase total riser force due to its nonlinear feature (the hysteresis feature). If the damping level is reduced by reducing the input electric current, the total riser force will be decreased but riser stroke will be increased. The favorable stroke reduction with marginal force increase may be designed by properly selecting optimal hysteresis parameters of the MR damper (e.g., Fig. 2), which is the subject of further study.

The effect of adding extra damper on mooring top-tension is not significant. In the Without Damper case, the maximum mooring top-tension is 4549.36 kN. With the introduction of linear or MR dampers, the top-tensions reduce to 4452 kN and 4472~4390 kN. The table above summarizes the maximum and minimum mooring top tensions (refer to Fig. 6 for leg information and location).

6. Conclusions

A new damper system (MR Damper), coupled with moderate-size low-heave semisubmersible, can be employed to reduce riser stroke to a manageable level to enable TTR-based dry-tree semisubmersibles. The low-heave semisubmersible with MR-damper provides favorable heave-motion and riser-stroke characteristics even for the most severe (1000-yr) storm condition. The damping level of the MR damper can actively be controlled by changing the energizing input electric current so that optimal current can be inputted for any given event, for example, to avoid huge force increase by impact loading of piston inside riser chamber. The expected penalty of using additional MR damper is that the MR-damper force can significantly be increased while it is to be resisted by MR fluid, while it little influences the pneumatic-riser force. Therefore, both the optimal design of MR damper-hysteresis-behavior and the proper input electric currents for target situations need to be applied for the best result. The platform heave motions are appreciably decreased after adding the MR damper. The mooring top-tensions are also reduced with the implementation of the MR Damper, but the reduction is not significant.

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Abbreviations

CHARM3D Texas A&M Ocean Engineering in-house finite element program for coupled moored offshore structures
GoM Gulf of Mexico
MR Magneto-Rheological
RAO Response Amplitude Operator
TTR Top-Tensioned Riser