Dynamic Analysis Of Single Deck Floating Roof With Deck Stiffeners

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Abstract - *Single deck floating roof (SDFR) is a circular steel plate with hollow section around its circumference, known as pontoon. It is one of the most commonly used roofing options for oil storage tanks. These roofs undergo severe damage during earthquake, which leads to the stored liquid to escape on to the surface and cause explosion. Thus the single deck floating roof needs to be strengthened, to reduce the damage inquired during seismic activity. Addition of stiffeners seems to be a simple solution for improving the stiffness of SDFR. This paper investigates dynamic stability of single deck floating roof, with and without deck stiffeners, for different patterns and diameters of roof.*

Key Words: Single deck floating roof, Deck stiffeners, Natural Frequency, Mode shapes, Numerical, ANSYS.

1.INTRODUCTION

Storage tanks had been widely used in many industries established particularly in the processing plant such as oil refinery and petrochemical industry. They are used to store a multitude of different products. The type of storage tank used for specified product is principally determined by safety, environmental requirement, operation cost and cost effectiveness. Floating roof tank, which remains buoyant over the surface of liquid, does not provide any vapor space beneath the roof. Absence of vapor space reduces emission losses, thereby reducing corrosion of the roof.

Floating roof tanks are more prone to damages during seismic activities. Damages caused by seismic excitations on these floating roofs cannot be overlooked, as it leads to sinking of the roof, buckling of pontoon and tearing off of sealing material between roof and tank wall. Several studies have shown that these damages was considerably less for double deck roof when compared to single deck roof, due to its rigidity as a result of the bulkheads. But use of double deck roof for large diameter tanks is highly uneconomical. Usually a single deck floating roof is adopted for tanks having diameter less than 50m. There comes the significance of strengthening the single deck floating roof.

Improving the rigidity, or more precisely the bending rigidity, of deck of the floating roof can be done by providing stiffening girders. This reduces out of plane deformation of the deck, thereby reducing horizontal deformation of the pontoon. Elliptical deformation of the pontoon, which caused the buckling failure of the floating roof, can be reduced to a certain extent by stiffening of the deck.

Studies regarding stress variation in roof provide an insight on the necessity of stiffening. But as can be seen majority of the literatures deal with addition of stiffeners in the pontoon, to reduce buckling failure of the pontoon rim [2]. Horizontal deformation of pontoon, which occurs during the second mode of sloshing, is mainly due to the radial compression of the deck plate [1]. If deck plate is stiffened enough to avoid the radial compression, buckling damage to the pontoon can be reduced. Amoung various deck stiffening patterns investigated concentric stiffener pattern and combination of concentric and radial stiffener pattern proved to be very effective in reducing the deflection of SDFR during static loading condition. Researchers also observed a similar behaviour for steel plates with stiffeners [3]. It was also found that rather than providing stiffeners in parallel orientation, intersecting stiffeners reduce the midpoint deflection of steel plates [5]. Addition of stiffeners also improves the natural frequency, thereby improving overall stiffness of steel plates [4].

2. NUMERICAL INVESTIGATION

Numerical analysis was done using ANSYS 16.0. SDFR tanks of diameter 30m, 40m, 50m, 60m and 80m were investigated. Geometrical dimensions and other required parameters of the different tanks are given in table 1. Angle section of size 100x100x10 mm [3] was provided.

Support condition of the roof was adopted by carefully analysing the behavior of roof during static condition and expected behavior during earthquake. Outer rim of the pontoon is in contact with the sealing material, which constraints the movement of floating roof in static condition. In order to re-enact the real world condition, the outer rim of pontoon was kept restrained. All remote displacements of the outer rim was kept constant.

A uniform mesh of fine relevance and high smoothing was used for having a more defined mesh, so that obtained solution is of highest accuracy.

The loads acting on the pontoon were calculated analytically using the equations derived by Goudarzi (2006). Only sloshing modes 1 and 2 were considered while computing the member forces, since the roofs were severely damaged in these two modes of sloshing. The velocity response spectrum value was assumed to be 100 cm/s [10]. The member forces acting on pontoon for roofs of different radii are given in table 2 .

Table-1: Specifications of considered tanks [10]

D_{tank} (m)	H_{liquid} (m)	$b_{pontoon}$ (m)	$h_{pontoon}$ (m)	t_{rim} (m)	t_{plate} (m)	ρ (kg/m³)
30	12	2.2	0.6	0.008	0.005	850
40	20	2.5	0.6	0.008	0.005	850
50	15	3	0.7	0.10	0.005	850
60	15	4	0.7	0.10	0.005	850
80	20	5	0.8	0.12	0.005	850

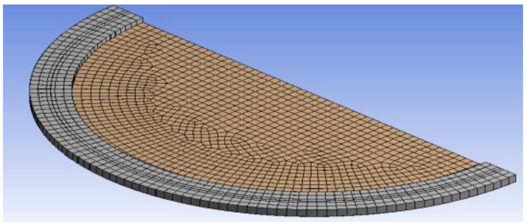


Fig - 1: Meshed view of SDFR

Table-2: Member forces (Mode 2) for roofs of different diameters

Diameter of roof (in m)	Horizontal in-plane bending moment (Mx) (in kNm)	Circumferential compressive force (Nθ) (in kN)
30	11.38	633.27
40	13.095	1262.6
50	18.06	1713.45
60	38.9	3365.69
80	91.75	6782.2

After application of forces, dynamic responses of model were investigated by modal analysis.

Models were analysed with and without deck plate stiffeners, arranged in different patterns, to optimize the most effective pattern in stabilizing the SDFR during seismic activity. Radial stiffeners (solid rectangular section) of size 250x3.2 mm and circumferential stiffeners (channel section) of size 250x50x3.2 mm [10] were adopted. Different patterns of stiffening investigated are given in Fig - 2.

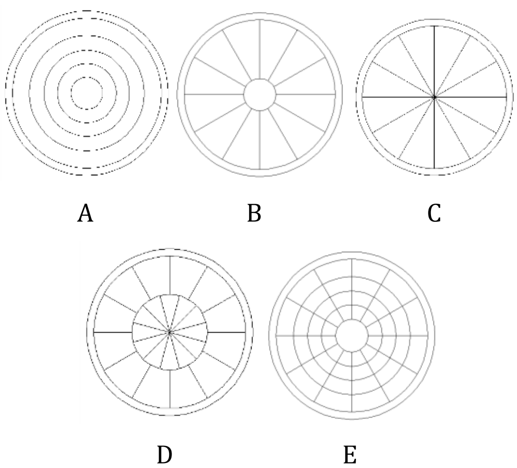


Fig - 2: Schematic representation of different patterns of stiffening

3. RESULTS AND DISCUSSION

The analysis that natural frequency of SDFR decreases with increase in diameter. Fig - 2 shows the relation between natural frequency and diameter of SDFR without deck stiffeners.

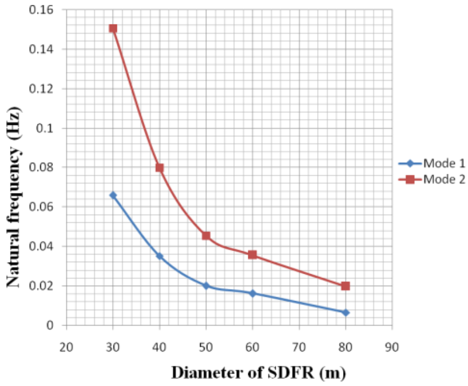


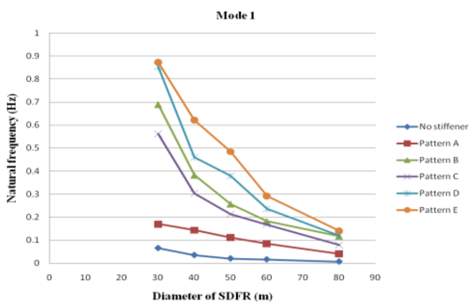
Fig - 2: Relation between natural frequency and diameter of SDFR without deck stiffeners

Table - 3: Mode 1 natural frequency of SDFR with different stiffener patterns for different diameters

Diameter of SDFR (m)	Mode 1 frequency					
	No stiffener	Pattern A	Pattern B	Pattern C	Pattern D	Pattern E
30	0.0659	0.1698	0.6899	0.5627	0.8532	0.8735
40	0.0352	0.1438	0.3822	0.3031	0.4603	0.6221
50	0.0201	0.1116	0.2566	0.2133	0.3789	0.4846
60	0.0162	0.0848	0.1811	0.1677	0.2352	0.2913
80	0.0065	0.0406	0.1164	0.0785	0.1188	0.1398

Table - 4: Mode 2 natural frequency of SDFR with different stiffener patterns for different diameters

Diameter of SDFR (m)	Mode 2 frequency					
	No stiffener	Pattern A	Pattern B	Pattern C	Pattern D	Pattern E
30	0.1506	0.4111	0.8731	0.8663	1.4532	1.4538
40	0.08	0.3391	0.4646	0.4606	0.5671	1.0915
50	0.0455	0.2655	0.2649	0.2639	0.5518	0.6555
60	0.0356	0.2304	0.2182	0.2168	0.3481	0.5202
80	0.0197	0.1824	0.1168	0.1152	0.1425	0.3099



(a)

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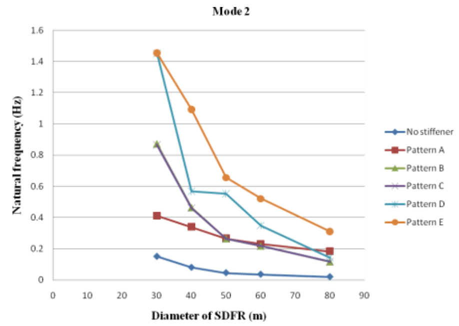
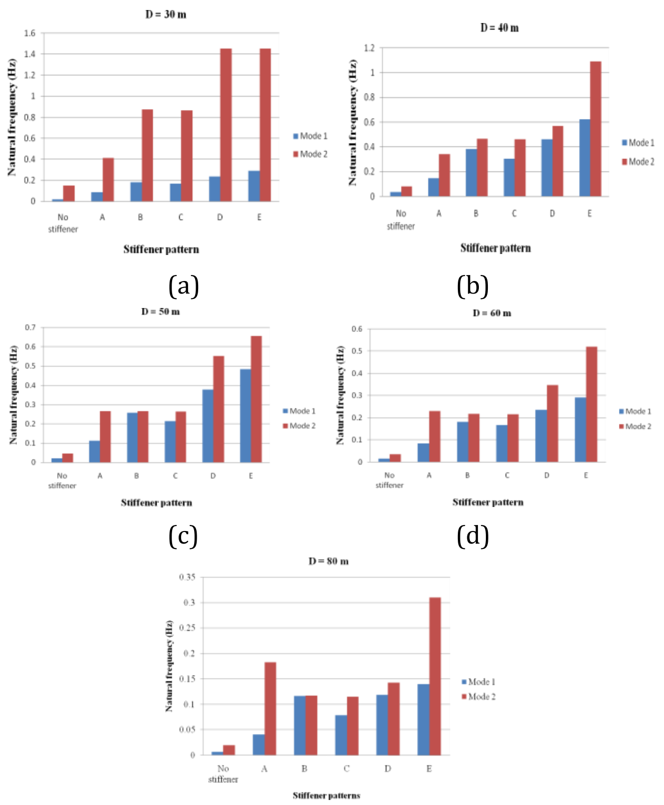


(b)

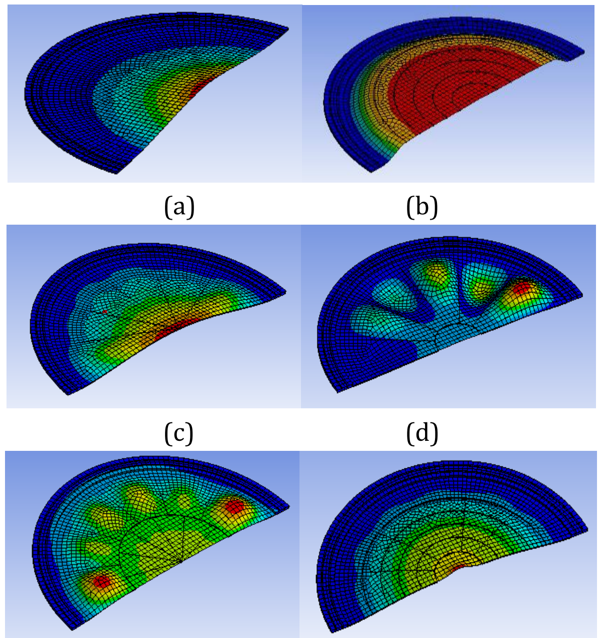
Fig -3: Relation between natural frequency and diameter of SDFR with different deck stiffening patterns for (a)mode 1 and (b)mode 2.



(e)

Chart -1: Comparison of natural frequency of SDFR of (a)30 m (b)40 m (c)50 m (d)60 m (e)80 m diameter for different deck stiffening

From Fig -3 it was found that pattern E showed maximum natural frequency. This is attributed to the fact that, more the number of stiffeners, more is the stiffness of the body. When pattern B and E are compared, the above statement can be verified. Different deck stiffening patterns for each diameter of SDFR is shown in **Chart -1.**

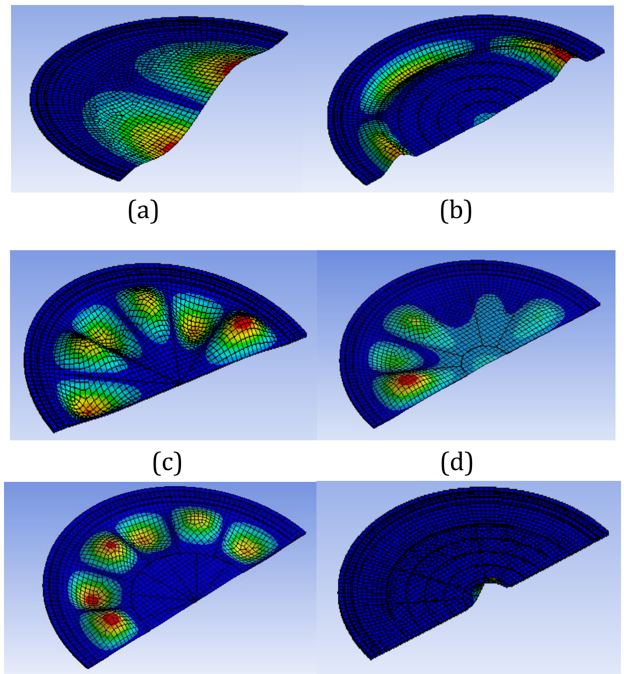


(a) (b)

(c) (d)

(e) (f)

Fig -4: Mode shapes SDFR with different deck stiffener patterns for mode 1.



(a) (b)

(c) (d)

(e) (f)

Fig -5: Mode shapes SDFR with different deck stiffener patterns for mode 1.

Mode shapes for both mode 1 and 2 was obtained as given in Fig 4 and 5. It can be seen that pattern E, a combination of concentric and radial stiffeners, offers more stiffness for SDFR, thereby providing more stability.

4. CONCLUSIONS

Dynamic responses i.e., natural frequency and mode shapes of SDFR with and without deck plate stiffeners, arranged in different patterns for different diameters were also analysed by modal analysis. Following are the conclusions derived from the studies conducted:

- Natural frequency of SDFR without deck plate stiffeners for different diameters was obtained and it was found that natural frequency decreased with increase in diameter.
- Analysis of SDFR with deck stiffeners arranged in different patterns for different diameters showed that natural frequency of SDFR increased when compared to that of SDFR without deck stiffeners.
- But natural frequency of SDFR with deck stiffeners reduced with increase in diameter.
- SDFR stiffened with pattern E was found to have the highest value of natural frequency.
- Mode shapes of SDFR, with and without deck stiffeners, for different diameters were obtained and pattern E was observed to be most stable.

Thus it can be concluded that stiffening of deck of SDFR with pattern E, i.e., combination of concentric and radial stiffeners, improves the dynamic response of the SDFR tank during seismic excitations.

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