Response control of higher modes of long-span domes using 2-segmented spine frames

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Abstract—**This study aims to investigate the seismic response of 150m span domes supported by multi-storey substructures. The effects of the post-yield stiffness of multi-storey substructures are analysed by considering two types of damped spine frames. Effects of incorporating 2-segmented spine frames in the substructure to control the higher mode response are also investigated.**

I. Introduction

This study investigates the seismic response characteristics of double layered long-span domes. The effects of the post-yield stiffness of multi-storey substructures are also analysed by considering damped spine frames.

II. Response Characteristics of Long-Span Dome

In this study, the double-layered lattice dome is modelled as a single-layered dome of 150m span (Figure 1), with half subtended angle of 30°. The dome consists of rigidly jointed circular hollow sections designed for a dead load of 3.0 kPa. The out-of-plane stiffness of the roof members has been adjusted to represent an equivalent double layered roof. The main vibration modes and natural periods of the dome are shown in Figure 2. When compared with the prominent vibration modes of a medium-span dome [1], the natural periods of these modes are longer, as seen by mapping these modes on the design spectrum [2]. Another inference is that the higher modes contribute significantly to the response of the roof and there is a need to include this effect to accurately estimate the peak design accelerations of long-span roofs.

III. Effects of Multi-Storey Substructure

The analysis models used in this study are representative of large-scale indoor stadiums or concert halls that are being increasingly realised. The effects of a multi-storey substructure on the roof response was analysed by considering dome models supported by a multi-storey substructure modelled using ETABS [3]. The substructure (Sub-Spine-MF) consists of a moment-resisting frame (MRF) with rigidly jointed beam-column connections enveloping spine frames that (Figure 3) utilize a stiff elastic braced steel frame with replaceable energy-dissipating members (BRBs) [4] inserted vertically (here, the BRBs are BRC). The spine frames are known to prevent damage concentration [5], and present simpler vibration modes. The frame sections and mass distribution are the same in all the models as summarized in Figure 3. In all the models, the moment frames are designed to remain elastic and the floors are assumed to be rigid. The two dominant modes of the combined models are shown in Figure 4. In the second mode of Spine-MF model, the O2 roof mode (higher mode) is excited.

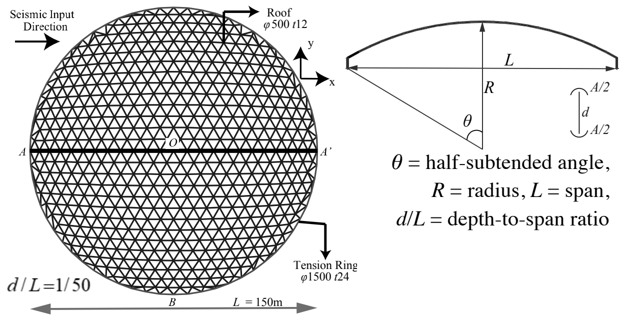

Figure 1: Plan view of the dome

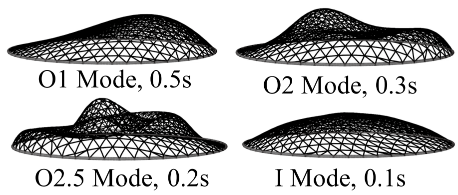

Figure 2: Four prominent modes of the dome

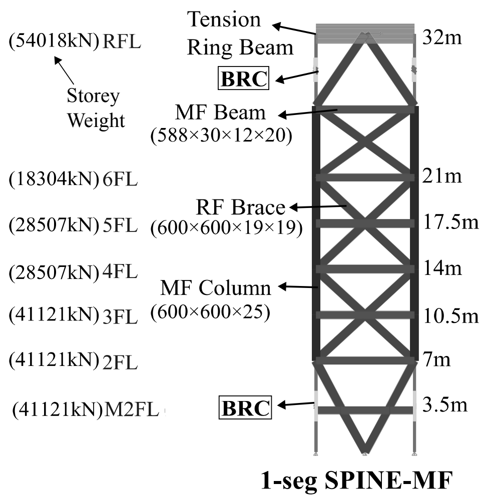

Figure 3: 1-seg damped spine frame

To investigate the effects of spine frame, NLRHA was performed on the model using four ground motions spectrally matched to the BRI-L2 design spectrum [6].The non-linear response history analyses (NLRHA) were implemented using the fast non-linear analysis method

(FNA) [3]. The acceleration distributions in the dome are shown later in Section 4 and the main parameters are given in Table 1.

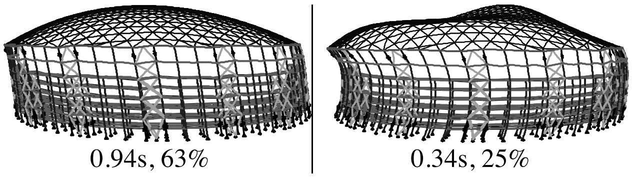

Figure 4: Two dominant modes of Spine-MF: Periods & mass participation

IV. EFFECTS OF 2-SEGMENTED SPINE FRAMES

Adding damped spine frames in the substructure proved to be effective in reducing the roof response. A reduction of about 40-50% in the horizontal accelerations and about 20-30% in the vertical accelerations was observed. However, this reduction was limited to the response derived from the first mode.

This suggested a need to introduce response control strategies that can also reduce the response in the higher modes. Therefore, additional analysis model (2-Seg-Spine-MF) with two segmented spines [7] were introduced (Figure 5). The floor at which the next segment was to be added was determined as per the floor with maximum modal displacement observed in the higher mode (in this case, the second mode) of the Spine-MF model.

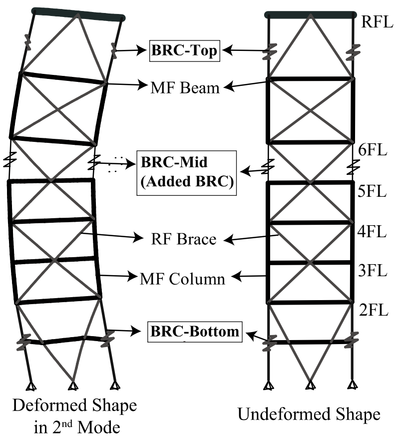

Figure 5: Section view: 2-Seg spine

Table 1: Main parameters of the analysis models

Mode m	β (%)	T (s)	D_h	K_{eq}/K_1	μ	T_{eq} (s)	A_{Heq} (cm/s^2)	A_{Veq} (cm/s^2)
(i) Spine-MF								
1	67	0.91	0.69	0.65	3.27	1.13	1000	1500
2	25	0.31	$\boxed{1.00}$	1.00	1.00	0.31	2200	2200
(ii) 2-Seg-Spine-MF								
1	66	0.92	0.65	0.59	2.91	1.13	900	1400
2	26	0.32	$\boxed{0.65}$	0.57	4.75	0.43	1900	2900 [3]

As shown in Figure 6, the average peak accelerations for 2-Seg spine models are lower than the 1-Seg spine model. The significance of higher mode with substructure in its higher mode and roof in O2 mode in the 1-seg model is clear from the peak response envelope. The change in the shape of the vertical acceleration distribution from 1-Seg to 2-Seg spine model indicates a transition from the O2 mode governing the response towards the predominance of the first mode (O1 mode) of the roof. The reduced D_h value [8] for the second mode of the 2-seg model in Table 1 confirms that response control strategies for higher modes can be employed to suppress the higher mode effects to a certain extent.

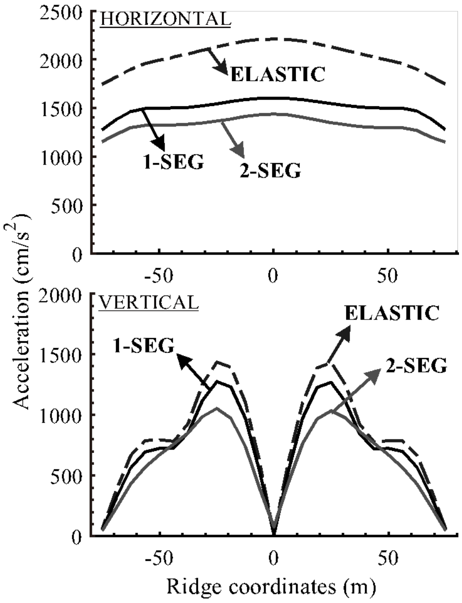

Figure 6: Comparison of peak average response

V. CONCLUSIONS

1. The contribution from higher vibration modes of multi-storey substructure and the long span roof lying on the constant-acceleration region of the design spectrum to the overall response can be significant.
2. The inclusion of spine frames in the substructure was proposed to simplify the vibration mode shapes of the substructure to ensure a uniform storey-drift distribution.
3. Incorporating a two segmented spine frame in the substructure was proved to be a convincing response control strategy to reduce the higher mode response. Yielding in higher mode provided additional energy dissipation reducing the overall response. Thus, the 2-seg spine frame is an effective solution for domed structures when the reductions in accelerations due to the 1-seg spine frame system are not enough.

References

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