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Seismic Analysis of Supplemental Cable Damping System in Transmission Masts

Neethi B.
Assistant Professor
Civil Engineering Department,
College of Engineering Muttathara,
Trivandrum, Kerala, India

Elsa Joby
Structural Engineer
Spacecase Architects and Designers, Erattupetta
Pala, Kerala, India

***Abstract*—Vast destruction and devastation during the recent earthquakes have exposed the serious deficiencies in the prevalent design and construction practices and have created new awareness about the disaster preparedness and mitigation methods. This paper presents the application of damage avoidance design philosophy to a steel mast, to develop an appropriate mechanism to mitigate the effects of an earthquake by using supplemental cable damping system with fuse-bars parallel to the dampers. Rigorous studies are conducted on the structure to develop a supplemental damping mechanism. The control system consists of supplemental dampers acting through a cable connected to the structure on the sides of the steel structure. The cable layout is determined iteratively based on the first mode characteristics to counteract the inertial forces in the structure, in a way to reduce the overturning moments.The concept development and design are carried out using capacity-demand spectrum method and is verified by nonlinear time history analysis using SAP 2000. Seismic performance and response evaluation suggests that a well designed supplemental cable damping system with fuse-bars can significantly reduce the vulnerability to damaging effects during an earthquake.**

Keywords*— *Capacity Demand Spectrum, Damage avoidance Design, Fuse, Mast, Pushover Analysis, Supplemental Cable Damping

I. INTRODUCTION

The current earthquake resistant design objectives are mainly achieved by enhancing ductility and structural strengthening so that it withstands the earthquake with some damage or severe damage, but without collapse. This implies that the damage should be controlled to acceptable levels and at reasonable costs. But this “ductile design” philosophy suffers from the inability to avoid damage during strong earthquakes. Even if the damages are moderate, the structure may be required to be taken out of service while inspection and repairs are undertaken. In order to meet these challenges, recent advances in Seismic Engineering have focused on an alternative design methodology; “Damage Avoidance Design” (DAD) philosophy, introduced by Mander and Cheng [3], where a structure is designed to withstand a major seismic event with minimal or repairable damages. This typically involves incorporating mechanisms in the structure that can control loads and sustain large deformations without causing damage.

This paper presents the application of damage avoidance design philosophy in a mast, to develop an appropriate mechanism to mitigate the effects of an earthquake by using supplemental cable damping system with fuse-bars parallel to the dampers. The control system consists of supplemental dampers acting through a cable connected to the structure on the sides of the steel structure. The cable layout is determined iteratively based on the first mode characteristics to counteract the inertial forces in the structure, in a way to reduce the overturning moments [4]. Rigorous studies are conducted on the structure to develop a supplemental damping mechanism. The concept development and design are carried out using capacity-demand spectrum method and is verified by nonlinear time history analysis using SAP 2000, to study the structural response of steel structure with and without supplemental cable damping systems and structural fuse-bars.

II. MODELLING & ANALYSIS OF STEEL MAST

A. *Mast Structure*

The mast structure used in this study is shown in Fig.1. The mast is with a height of 50 m; with vertical members (2 ISA 130x130x10), cross braces (ISA 70x70x8) and mast body (ISA 90x90x6) of density 7849 kg/m^3, Young’s modulus, E 199947.48 N/mm^2 and Poisson’s ratio 0.3.The first 3 mode shapes and their respective time periods are given in Fig.2. A response spectrum analysis was performed on the structure. The mast is analyzed for El Centro spectrum. It is observed that in the direction of U1 degree of freedom, the maximum displacement is 0.147004m.

B. *Mast with cable*

An electric mast is modeled with cables [1], [2] of diameter 0.0287m in SAP 2000 as shown in Fig.3.The first 3 mode shapes of the mast structure with cables are 0.46849 sec, 0.37402 sec and 0.26482 sec respectively. A response spectrum analysis was performed on the structure. The mast is analyzed for the El Centro spectrum. It is observed that in the direction of U1 degree of freedom, the maximum displacement is 0.019785m.

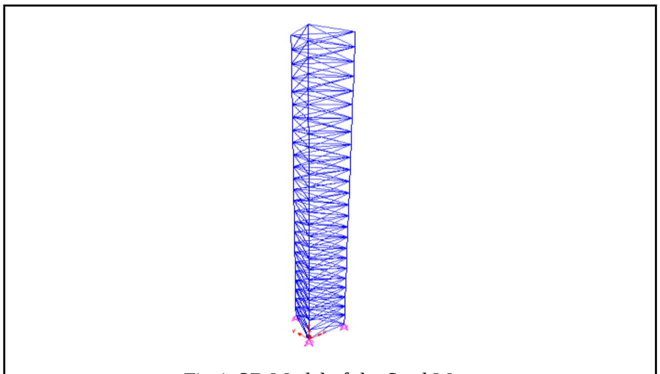


Fig.1. 3D Model of the Steel Mast

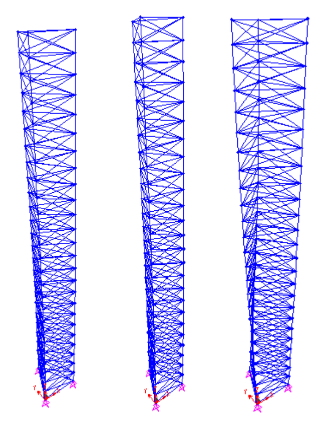


Fig.2. First 3 mode shapes of the steel mast of time periods 0.77867 sec, 0.68373 sec and 0.40106 sec respectively.

C. Discussion of Proposed Configuration

An approximate supplemental cable damping system is chosen by taking into account the dominant mode shape of Steel structure, and is fixed on either side of the structure. The structure is analyzed for El Centro (1940) ground excitation. The procedure is continued by varying the supplemental damping parameters and cable profiles and number of supplemental cable damping system till there is a significant reduction in the seismic response of the structure. The obtained near optimum cable layout and supplemental cable dampers parameter from iterative method is given as:

Damper Stiffness K-1926.39 KN/m
Damping Coefficient C-3.71 KN-S/m
Damping exponent α-0.2
Cable diameter-28.6608mm

D. Implementation of structural fuse system

The required fuse behaviour is obtained by defining the hinge property in the fuse element hence above a threshold magnitude of earthquake; the fuse will yield first and keeps the structure, supplemental damping system elastic [5],[6],[7]. Thus fuse properties can be chosen, based on the performance objectives, and hinge properties can be set. Table 1 shows the reduction in floor displacement due to the deployment of structural fuse system.

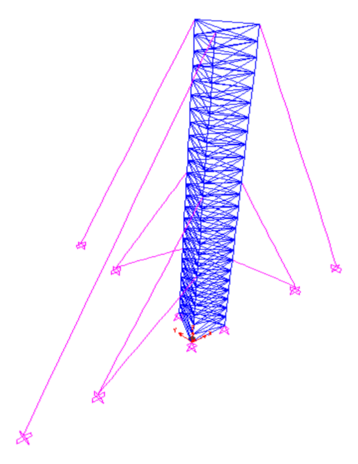
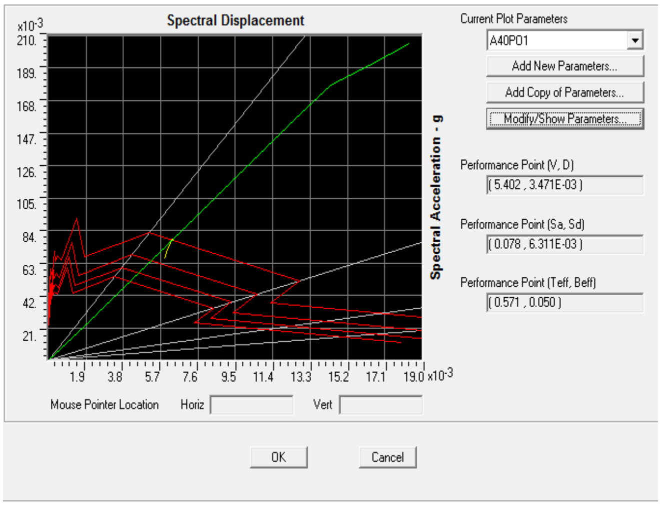


Fig.3. 3D Model of the Steel Mast with cables

E. Nonlinear Seismic Response (Pushover analysis) of the Steel mast

A nonlinear pushover analysis is performed on steel structure with and without supplemental cable dampers and structural fuse-bars. Fig.4 shows the capacity demand curves of steel structure. Fig.5 shows the state of the structure at performance point.

Fig.6 shows the capacity demand curves of steel mast with supplemental dampers and fuse-bars. Fig.7 shows the state of the mast with supplemental dampers and fuse-bars at performance point.



Current Plot Parameters: A40P01

Performance Point (V, D): (5.402 , 3.471E-03)

Performance Point (Sa, Sd): (0.078 , 6.311E-03)

Performance Point (Teff, Beff): (0.571 , 0.050)

Fig.4. Capacity demand curves of steel mast

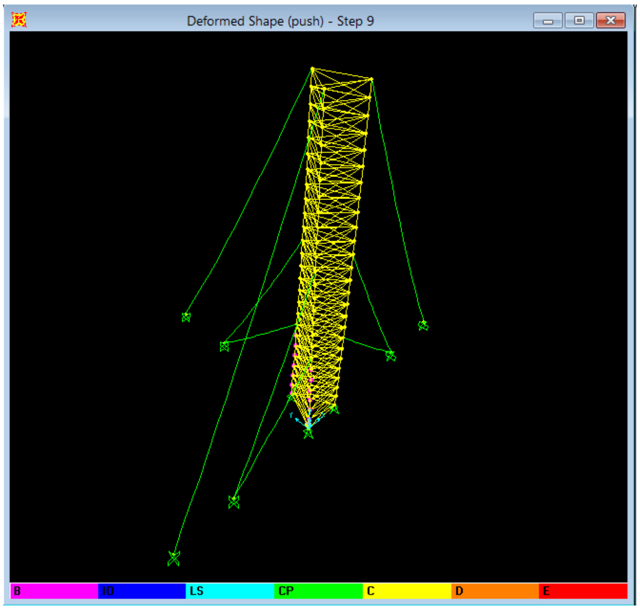
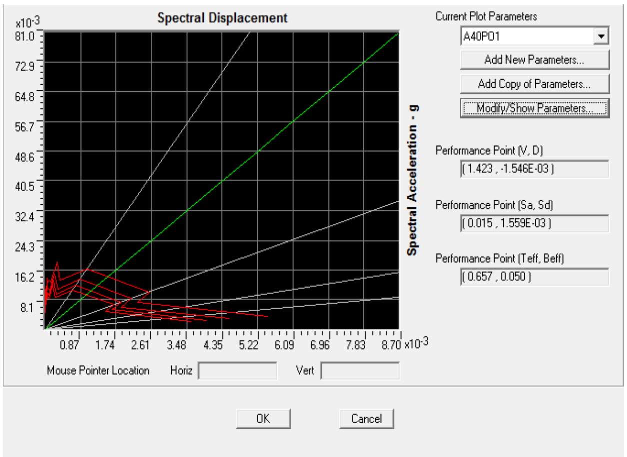


Fig.5. State of Steel Mast at performance point

F. Evaluation of Seismic Performance of the Mast

It is observed from the pushover analysis of Steel mast that at performance point time period (T_{eff}) is 0.571 sec and the corresponding deformation step falls in between step 8 and 9. Performance of the structure is within operational level. In case of structure with supplemental cable damping system, the capacity against demand showed a significant improvement. The performance point time period (Teff) observed to be 0.657 sec .The corresponding deformation step shows that structure behaves elastically without any hinge formation at performance point. The displacement at the performance point reduced from 0.003471m to 0.001546m, when supplemental cable damping system with fuse bars parallel to the damper is applied on the steel structure. Thus it can be concluded that the supplemental damping systems with fuse bars parallel to the damper have improved the global behaviour of the structure.



Current Plot Parameters: A40P01

Performance Point (V, D): (1.423 , -1.546E-03)

Performance Point (Sa, Sd): (0.015 , 1.559E-03)

Performance Point (Teff, Beff): (0.657 , 0.050)

Fig.6. Capacity demand curves of steel mast with supplemental dampers and fuse-bars

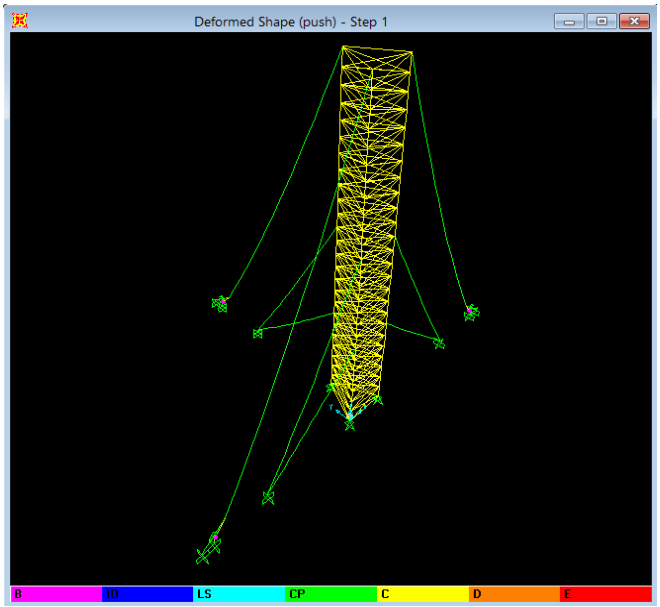


Fig.7. State of Steel Mast with supplemental dampers and fuse-bars at performance point

III. SUMMARY

Seismic performance is measured by the state of damage under a certain level of seismic hazard. Non-linear time history analysis of the steel mast shows that with the deployment of supplemental damping system with structural fuse bars in parallel to these dampers in the structure, the maximum lateral displacements got reduced from 0.126781m to 0.031286m. It’s seen from the study that Structural fuse bars in parallel to the supplemental cable damping system can reduce maximum lateral displacement in the steel mast to 0.25 times of that of steel mast without supplemental damping system and structural fuse bars. Cable layout is determined iteratively based on the first mode characteristics is fairly sufficient in counteracting the inertial forces.It is observed from nonlinear pushover analysis that, supplemental damping system has improved the capacity of the steel structure.Thus it can be concluded that the supplemental damping systems can improve the global behaviour of the structure.Hence a with fuse-bars can reduce the to damage during a seismic event.

IV. CONCLUSION

Analysis and design of masts against earthquake effect is very important by using DAD Philosophy. Recent and promising advances in the field of Seismic Engineering are “Damage Avoidance Design” (DAD) philosophy to improve the seismic performance for mast like structures. Steel Mast using a supplemental cable damping system with structural fuse provides a cost-effective way of controlling structural deformation and damage under earthquake excitations. The structural fuse can be readily replaced after a major earthquake without interfering with the primary structural system. The structural displacement reduces 0.25 times of that of mast without the supplemental damping system and fuse-bar when excited for El Centro spectrum. Supplemental damping systems with structural fuse are simple, and exhibit reliable characteristics which can be adopted to enhance the seismic performance of the structure.The study shows that the performance of supplemental cable damping system and structural fuse bars are satisfactory in improving the response of the structures.

APPENDIX A: NUMERICAL EXAMPLE FOR DESIGN OF SUPPLEMENTAL CABLE DAMPING SYSTEM

1. The target design drift θ_{max} is chosen as 1% for a 500 year event.
2. Target displacement, $X_{max}=\theta_{max}. H_{eff}=0.01x=0.7x50=$ 0.35m
3. Iteration

a. Assume total effective damping $\xi^{tot}_{eff}=26.4\ \%$

b. Spectral amplification factor $B_l=$ $\left(\frac{\xi\ tot\ eff}{0.05}\right)^{0.3}=\left(\frac{0.264}{0.05}\right)^{0.3}=1.647366$

c. Structural demand $C_d=\left(\frac{S_a}{2\prod B_l}\right)^2\left(\frac{g}{Xmax}\right)$ =0.065351

d. Capacity of bare structure = C_C^{str} =0.041

e. Capacity of supplemental System required = $C_C^{sup}=C_d-$ C_C^{str} =0.024351

f. Supplemental damping ξ_d required is equal to =0.93 $C_c^{sup}(X_{max})^{0.04}(C_d)^{-0.84}=21.47\%$

g. Total effective damping $=\xi^{tot}_{eff}=\xi^{str}_{eff}+\xi^{fr}_{hy}+\xi_d$ $=5\%+0\%+21.47\%=26.47\%$

4. For the cable damper with structural fuse configuration, the supplemental capacity is divided between the dampers and fuses as

$$C_C^{sup}=C_C^d+C_C^f$$

Therefore C_C^d =Capacity provided by the dampers= 13.235% and C_C^f = Capacity provided by the fuse=13.235%.

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