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ABSTRACT

Nowadays light rail transit (LRT) system is more desired to use due to improvement of travel option, sustainability and facilitating swift mobility in urban area. Hence, structural stability and safety of these public transportation systems against the seismic occurrences is indispensable. Since, these structures cannot be considered as conventional frames due to complex architectural design, therefore in order to design for lateral resistance system, it is vital to focus meticulously on reliable seismic design codes and structural rehabilitation techniques. In the present paper, the LRT station located in Malaysia is considered and seismic response of train station with supplementary viscous damper devices is evaluated. So, LRT station is modeled using finite element simulation. The developed model subjected to multi support excitation and time history analysis was considered. The seismic response assessment is reported in terms of structural displacements as well as base shear. The result indicated that implementing viscous dampers have a significant decrease in response of structure during earthquake excitation. Maximum value of displacement and base shear are declined by approximately 40% and 60 % respectively in model equipped with dampers compared with bare model. The efficiency of implementing damper device in seismic response of LRT structure has been proved.

KEYWORDS

Brace viscous damper, time history analysis and light rail transit.

INTRODUCTION

The generic use of light rail transit (LRT) were desired in last decades due to improvement of travel option, sustainability and facilitating swift mobility in urban area. Hence, human safety of these public transportations against the seismic occurrences is indispensable. Since, these structures cannot be considered as conventional frames due to architectural complexity, so it is vital to focus meticulously on reliable seismic design codes and structural rehabilitation. In contrast, a misconception by
Malaysians that the country is free from earthquake disasters, become the main concern of engineers in Malaysia to analyze and design structures that could resist an earthquake as well as retrofitting the existing structures.

Peak ground acceleration (PGA) plays an important role for design and earthquake load determination. On the other hand, since Malaysia has not any reliable and economic seismic code, the local engineers utilize the recommendations from available international codes to determine the seismic loads applied. The direct application of the international standards such as the UBC 1997 or the AASTHO 1996 to determine these loads have resulted in high construction cost due to the overestimation of PGA for Malaysia region because of insufficient data. A Lam stochastic model was introduced to simulate the elastic response spectra (of 5% critical damping) of large magnitude long distance earthquakes generated by the Sunda Arc subduction source in Indonesia (Lam et al. 2009). A new set of attenuation relationships for PGA, peak ground velocity (PGV) and response spectrum analysis (RSA) on rock site due to distant Sumatran-subduction earthquakes have been derived for Singapore and the Peninsular Malaysia based on synthetic seismograms that account for source and path effects (Megawati et al. 2003; 2005). Previous study investigated the potential effective factors on structure response to multi-directional earthquake loading such as site ground response, variation of water table and soil properties (Yang and Yan 2009). The spatial effects on the seismic responses of two-line supports large space structures were studied. The three-dimensional variation of ground motion was modeled by an empirical coherency loss function. Numerical outcomes specified that horizontal multi-support excitations have a quite large amplification effect on the seismic responses of the trussed arch (Su et al. 2006; 2007). In this present paper the seismic response of LRT station which is located in Kuala Lumpur, Malaysia is evaluated. Time History analysis performed by modeling of structures with and without brace viscous damper performed by aid of Structural Analysis Program (SAP 2000). Efficiency of SAP 2000 application in dynamic analysis has recently been verified by previous studies (Behnia et al. 2013).

MATERIAL AND METHOD

Case Study Detail

The station structure was supported by three RC column piers to the foundations located on road shoulders. The spacing between the column pier supports orthogonal to the carriageway & guide way structure varies between 13.0m and 16.5m and is repeated every 12.0m along the viaduct piers. The station consists of steelwork, fabricated plated steel sections spanning continuously between RC piers supporting simply supported precast pre-stressed hollow core slabs over 12m spans. The steel girders are supported on laminated elastomeric bearing pads to reduce the risk of damage to the RC piers due to the rotation of the beams being loaded. A series of one-way and two-way spanning RC slab framework spanning onto in-situ RC beams which in-turn were supported by RC columns. The design was independent of the viaduct structure to avoid any dynamic loads from the rail propagating into the station structure. The roof was pinned or fixed to curved truss frame, stable in its own plane by virtue of moment continuity throughout and exhibited globally 1 to 3 degrees of statically indeterminacy. Base was resisted with the employment of a continuous plate girder which effectively acts as the base tie. On-elevation lateral stability in the orthogonal direction to the plane of the frame was provided by on-elevation tie-bracing and / or moment frame trusses /beams. Roof diaphragm action was ensured with the employment of on plan tie-bracing and roof sheeting. For the stations constructed of reinforced concrete, the rigid connection between the RC girders and piers ensured a portalized framing on-elevation lateral stability configuration. The on-elevation lateral stability between the concourse level and the platform was again provided by the inherent moment connections between the in-situ RC columns and beams. The building was founded on RC pile caps and in-situ bored RC piles. Tie-beams between these pile caps were employed to resist the pile out-of-tolerance moments and ensured robustness and rigidity. These tie-beams also resisted bending action resulting from vehicular impact loading.
Software Model Detail

This research was merely based on the modeling techniques and abilities of the synonymous SAP2000. As illustrated in Figure 1, the model comprises a 3D space frame model which was founded on fixed supports. Two models were created to represent the station with and without dampers. The models were analyzed based on linear dynamic time history analysis.

![3D and elevation view of Space Frame without Damper](image1)

![3D Space Frame with Damper](image2)

Figure 1. 3D Space Frame Model with and without Damper

Loading Details

The material densities adopted in the calculation of loads based on the British Standard, BS 648:198. Due to the relative low-rise nature of the station buildings, live load reduction in accordance with BS 6399-1:1995 was not applicable. Wind loads were calculated in accordance with BS 6399-2 as well as the Malaysian Standard, MS 1553:2002. Vehicular impact loads were considered for the design of the primary station piers over the vehicular trafficked roads to British Standard, BD 60, which stipulated an equivalent static load of 1000kN at 3.0m and 500kN at 1.5m above the carriageway level for the parallel to traffic direction, and half the above values for the orthogonal direction. All structures were designed for the worst combination of loading. Different load combinations were taken into account to fulfill ultimate limit state (ULS) and the serviceability limit state (SLS) criteria which are based on the BS 8110 and BS 5950.

Construction Material and Structural Control Specifications

In the reinforced concrete elements, all longitudinal reinforcement bars type 2 deformed grade T460, i.e. threaded rebar of minimum characteristic yield strength of 460 N/mm² were used. Shear links were to be grade R250, i.e. plain rebar of minimum yield strength of 250N/mm². Mesh reinforcement, BRC minimum characteristic yield strength of 485 N/mm². Grades and properties of hollow core slab were based on a renowned prefabricator, Eastern Pretech (Malaysia) Sdn. Bhd. In addition to, The properties of the damper are based on previous study conducted (Panah et al. 2008), with damping coefficient of 490 KN m/s, Brace stiffness of 98066 KN/m and Brace-damper Mass of 1360 KNs²/m.

Seismic Analysis and Software Modeling Procedure

General overviews of different analysis methods are illustrated in Figure 3. To determine the modes of vibration of the LRT Station, the Modal Analyses were performed. The modes were also used as the basis for modal superposition in Time History analysis cases. In the modal analysis, the structural system of the LRT station was relatively regular and suitable for either a single dominant modal
response analysis or a multi-modal response analysis. To evaluate the response of all modes of vibration with significant contribution to the global response, the following conditions were taken into account and should be satisfied for each direction as stated in Euro code, EC8:

i) The effective modal masses for the modes considered shall at least be 90% of the total mass of the structure and, ii) All modes with effective modal masses greater than 5% of the total mass to be considered. Modal Analysis which defined the fundamental modes inclusive of participating masses was established for both un-damped and damped structures. A linear time history analysis of the LRT Station which considered the El Centro, 1940 earthquake as 3-Directional excitation (X, Y, and Z) was performed. The displacement and base reactions were the benchmark for the comparison.

RESULTS AND DISCUSSION

In order to check the response of the proposed models in linear static and dynamic analysis, it was necessary to compare the following parameters: 1) First three natural vibration periods of the sample buildings, 2) Participating mass ratios, 3) Displacements of the building and, 4) Base shear of the building. Understanding the modeling features was paramount to get an idea before viewing the results of all the analyses. Figure 2 shows the essential elements to grasp the important features of the model.

![LRT Station FE 3D Model](image)

**Figure 2. LRT Station FE 3D Model**

**Modal and Linear Time History Analysis**

Twenty Eigen modes were selected during the pre-analysis, with their equivalent frequencies and periods calculated. The dominant period for un-damped case is equal to 1.594 sec whereas for damped case is equal to .938 seconds. Time History Analysis performed on the X, Y & Z directions for the station building structures and the displacement along with the base shear results were evaluated for both models (damped and un-damped). The acceleration-time record of El Centro Earthquake was applied directly to the base of the station building structure for both models in all three directions. Upon observation, both the lateral directions (X and Y) excitation yield significant responses. Despite this, the vertical directional (Z) excitation indicates no significant change in the responses. Time history response at each joint has been derived from the analysis. The results showed a limited response of the LRT station for 20 sec of the entire duration of the earthquake which is 50 sec. Regardless, the critical components of the earthquake falls within the first 20 sec. The results obtained are not only the maximum responses but it was a time-dependent function hence a dynamic response can be plotted out with respect to time. Similarly as per the response spectrum analysis, four (4) joints were chosen to display its response to the time history excitation. Figures 3&4 showed the displacement response for X and Y directional earthquake excitation in relation to the damped and undamped models at different locations. It is clear that the provision of viscous dampers have a significant decrease in response. Two joints at the top of the tubular roof structure (Joint 1525 and joint 1634) indicate an approximate of 40% reduction for the damped condition even though the damper was not physically connected to any part of the roof structure. Furthermore, two joints at the tip of the RC column/piers (Joint 2219 and Joint 2215) illustrated an approximately 90% reduction for
the damped condition. Unlike the roof joints, column at joint 2215 is directly connected to the damper allowing for more dissipation of energy in turn reducing the displacement significantly. Figure 5 demonstrates the base shear time dependent graphs obtained by time history analysis in X and Y directions for the two models (damped and un-damped). The comparison against both the un-damped structure and damped structures indicates an approximate of more than 60% reduction in Y-direction and 71% in the X-direction in accordance to the overall base shear.

![Figure 3: Time History displacement for joints 1525 & 1634, roof top node](image)

![Figure 4: Time History displacement for joints 2215 & 2219, RC column top node](image)

![Figure 5: Time History of Base Shear](image)

**CONCLUSION**

The seismic behavior of the structure in terms displacement and base shear were determined and the numerical results for the two models (un-damped and damped) evidently indicated that the dampers reduce the seismic response of structures in an extremely efficient way. First point for comparison is the joint at the top of the structure which shows that the horizontal displacements in damped model are reduced by 40%. Consequently, the joint at the top of the column/pier's horizontal displacements and base shear are decreased by 90% and 65% respectively. The benefits of damper application in LRT station have been visibly demonstrated by the above comparative data and there is an improvement in performance of structure during an earthquake excitation.
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