Application Research of Liquid Viscous Damper in Controllable Structure

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Abstract: The controllable structure assembling the additional liquid viscous damper shows good structural characteristics through theoretical analysis and the comparison with model test. Liquid viscous dampers can significantly change the basic dynamic characteristics of the structure and exhibit certain regularity. According to the research, the ability of the structure assembling damper to adjust itself is greater than the effect of same structure adding weight, which indicates that the liquid viscous damper plays a prominent role in controlling the structural response.

1. Introduction
The safety of building structures has always been the focus on attention in the field of structural engineering. The academic community has made a lot of research in exploring different structural styles and improving the vibration control performance of buildings. The mega-sub controlled structural system (MSCSS) is a new type of structural system that integrates structural response control functions into the structural system itself. MSCSS combines the theory of frequency modulation sub-structure control with the construction method of mega frame structure (MFS). By relaxing the constraint between the main-structure and the sub-structure of the mega frame, MSCSS gives the sub-structure quality frequency modulation function and further strengthens control effect by setting the viscous dampers.

Domestic scholars have conducted in-depth research on this type of structure and achieved a lot of results. The results show that there are some influencing factors which get a significant effect in the controlling of the displacement and acceleration response on the mega-sub controlled structural system, such as the mass ratio of the mega-sub structure, the stiffness ratio of the mega-sub structure, the stiffness of the additional column, the shear stiffness ratio of the sub-structure, the damper efficiency and the damping ratio of the sub-structure [1] [2]. On the basis of relevant research, I used the method of reliability analysis to study the influence of the additional damper arrangement on the controlled structural system and propose an optimal layout scheme [3]. Our research group developed an adjustable liquid viscous damper, according the model simulation analysis and physical test analysis, determined its mechanical properties and established a modular analysis model [4].

In this paper, the experimentally matched damper analysis model is firstly arranged in the controllable structural model according to the physical assembly scheme for elastic time history analysis, and compared with the ordinary mega frame structure. On this basis, the shrinkage model is made according to different structure systems and damper arrangement schemes, as it’s shown in Figure 1. The seismic performance of the structural model excited by real seismic waves is simulated.
by experiments and compared with the calculated analysis results. The methods and conclusions make up for the verification of relevant theories in the physical model test, and it also can provide an important reference for promoting the controllable structural system to play its role in engineering applications.

Figure 1. Assembling of structural model.

2. Arrangement of Dampers and Structural Calculation Analysis

2.1 Structural model

Building a mega frame structure and mega-sub controlled structure in order to explore the influences of the liquid viscous dampers assembled on the structure about structural dynamic characteristics and the reducing of vibration response. Both of the structure systems consist of a 4-layer mega-structure, which is consisting of a giant column and a giant beam layer. The difference between two kinds of structural system is the relaxing of some parts on structures, assembling with dampers, which making sub-structure contained in mega-structure in the MSCSS, as it’s shown in figure 2.

Figure 2. Structural comparison of MFS and MSCSS.

According to the previous research results, considering the assembly conditions of the physical model, both of the model about original structure and the structure with additional damping weight are made, which are respectively recorded as MFS1 and MFS2. The dampers are arranged on the top of the maximum displacement response of the sub-structure in each controllable structure. The following three schemes are formed: MSCSS0001 arranges the additional damper on the top layer of the sub-structure in the first (top) mega-structure. MSCSS0010 arranges the additional damper on the top layer of the sub-structure in the second mega-structure. MSCSS0100 arranges the additional damper on the top layer of the sub-structure in the third mega-structure, as shown in figure 3.
2.2 External incentives
In order to analyze the practical application of the viscous damper in the controlled structure effectively, the time-history analysis method is used to reflect the dynamic response of the building structure under earthquake action. For achieving the intended purpose, combined with the statistical properties of the double non-stationary seismic waves, El-Centro (N-S) wave, Qian'an (N-S) seismic wave, TAFT (S-E) seismic wave are selected as external excitation.

2.3 Calculation results
Three original seismic waves are loaded through the vibrating table, and the model structures are excited multiple times. Analysis the data which is the closest to the horizontal sliding table. The results are shown in tables 1 to 3.

As it’s shown in the table below, the following conclusions are drawn. The velocity response is different under different seismic waves on the same structure, in some cases, the relationship between them is not same exactly. Additional liquid viscous dampers assembled on the MSCSS has a good control effect on the structural response. There has been a significant improvement about response control effect on the layer of mega-structure assembling the liquid viscous damper. The lower liquid viscous dampers is assembled, the much control effect is reduced on the MSCSS.

Table 1. Structural velocity response under El-Centro (m/s).

|        | Top of the first mega-structure | Top of the first sub-structure | Top of the second mega-structure | Top of the second sub-structure | Top of the third mega-structure | Top of the third sub-structure |
|--------|---------------------------------|--------------------------------|----------------------------------|--------------------------------|--------------------------------|-------------------------------|
| MFS1   | 0.0701                          | 0.0687                         | 0.0566                           | 0.0550                         | 0.0448                         | 0.0424                        |
| MSCSS0001 | 0.0358                          | 0.0359                         | 0.0308                           | 0.0306                         | 0.0270                         | 0.0257                        |
| MSCSS0010 | 0.0378                          | 0.0369                         | 0.0317                           | 0.0315                         | 0.0278                         | 0.0264                        |
| MSCSS0100 | 0.0598                          | 0.0582                         | 0.0485                           | 0.0523                         | 0.0384                         | 0.0370                        |
Table 2. Structural velocity response under Qian’an (m/s).

|                     | Top of the first mega-structure | Top of the first sub-structure | Top of the second mega-structure | Top of the second sub-structure | Top of the third mega-structure | Top of the third sub-structure |
|---------------------|---------------------------------|--------------------------------|---------------------------------|---------------------------------|---------------------------------|--------------------------------|
| MFS1                | 0.3135                          | 0.3069                         | 0.2479                          | 0.2381                          | 0.1612                          | 0.1494                          |
| MSCSS0001          | 0.2169                          | 0.2174                         | 0.1877                          | 0.1821                          | 0.1329                          | 0.1246                          |
| MSCSS0010          | 0.2248                          | 0.2204                         | 0.1921                          | 0.1862                          | 0.1341                          | 0.1256                          |
| MSCSS0100          | 0.1582                          | 0.1539                         | 0.1288                          | 0.1361                          | 0.0963                          | 0.0903                          |

Table 3. Structural velocity response under TAFT (m/s).

|                     | Top of the first mega-structure | Top of the first sub-structure | Top of the second mega-structure | Top of the second sub-structure | Top of the third mega-structure | Top of the third sub-structure |
|---------------------|---------------------------------|--------------------------------|---------------------------------|---------------------------------|---------------------------------|--------------------------------|
| MFS1                | 0.0356                          | 0.0349                         | 0.0291                          | 0.0280                          | 0.0186                          | 0.0174                          |
| MSCSS0001          | 0.0287                          | 0.0287                         | 0.0244                          | 0.0236                          | 0.0166                          | 0.0155                          |
| MSCSS0010          | 0.0296                          | 0.0291                         | 0.0248                          | 0.0240                          | 0.0169                          | 0.0157                          |
| MSCSS0100          | 0.0348                          | 0.0343                         | 0.0298                          | 0.0302                          | 0.0201                          | 0.0188                          |

3. Structural model test and comparative analysis with simulation calculation

3.1 Checking of structural dynamics

Limited to the length of this paper, only the MSCSS0001 structural model with obvious control effect and MFS1 are selected as the comparison object. Firstly, the accuracy of the finite element simulation is verified by the calculation of the natural vibration frequency in the dynamic characteristics. The comparison results are shown in table 4.

The results show that the calculated values agree well with the measured values at the low-order natural frequency. The self-vibration frequency in the horizontal direction is better than the rotational frequency. According to the analysis, it is necessary to couple the vibration characteristics in two directions when performing modal measurement. In the process, the error is accumulated and amplified, and the simple X direction and the Y direction are less affected by the other direction, which makes the error smaller. At the same time, it should be noted that some of the pre-stresses existing in the assembly process of the model and the non-strict symmetry in the two directions will cause large errors in the rotational mode.

Table 4. Comparison between the calculated values and the measured values.

|               | MFS1 | MSCSS0001 |
|---------------|------|-----------|
| calculated    |      |           |
| values        | 6.945409 | 6.783 | 2.34% | 5.676658 | 5.130 | 9.63% |
| measured      | 6.945409 | 6.883 | 0.90% | 5.676658 | 5.313 | 6.41% |
| error         | 17.46115 | 13.448 | 22.98% | 17.4703 | 9.587 | 45.12% |
| calculated    |      |           |
| values        | 21.54708 | 13.448 | -0.65% | 18.2615 | 13.716 | 24.89% |
| measured      | 21.54708 | 21.810 | -1.22% | 18.2615 | 14.166 | 22.43% |

3.2 Test results and comparative analysis

According to the response amplitude at the key control points, the difference in vibration control of different structural patterns can be demonstrated, and the vibration of the real reaction structure under simulated earthquake action can be obtained. In this paper, a large number of synthetic artificial waves
[5] are used to excite the time-history curve, and the results are compared with the calculated values to comprehensively analyze the relationship between the two kinds of structural systems. The following comparison will be made from the response of external excitation at two key points in the structure.

The two comparison curves can reflect the real-time response of the structure well, and the overall vibration trend is strictly consistent in figure 4. The high-level contrast curve of the structure is not as good as the lower layer, but the overall statistical mean characteristic is better than the speed comparison relationship under the action of a single seismic wave. At the same time, it can be seen that after the statistical processing of a large amount of data, the response can still maintain a certain value with the original wave, which also confirms the rationality of generating artificial waves in this paper.

It can be seen from the velocity standard deviation in figure 5 that the discreteness of the structural velocity response data is maintained at a good level based on a large number of artificial wave excitations. The standard deviation of less than 0.06 indicates that the response control characteristics are very stable under the excitation of each artificial wave in both of the test value and the calculated value. The curve of test value and the calculated value curve has a high degree of agreement, indicating that the result is credible.

Due to the inaccuracy of the vibration threshold of the vibrating table and the long test period, it is difficult to ensure that the amplitude of the same wave is constant after loading the different waveforms on the vibrating table cyclically.

Although the error is very small, in order to visually express the response characteristics of the structure under external excitation, creating a $\beta$ values to describe the ratio of the excitation of each
layer and each structural model under the EI-Centro wave, the Qian'an seismic wave and the TAFT seismic wave and the corresponding mesa acceleration. Figure 6 is a comparison of the β values of five structural models excited by different seismic waves.

It can be seen from figure 6 that the mega-sub controlled structure system can control the response amplification well, although in the control process, there are some parts in which the speed response control is not good enough. But the acceleration is smaller than the mega frame structure, and compared with MFS2, it has a good control effect. By responding to the amplification factor, it is found that the partial structure pattern has a phenomenon that the mega-structure response is smaller than the sub-structure response. The analysis considers that the horizontal connection between the sub-structure and the mega-structure is interrupted and only the vertical layer exists. When the mass of the damper is large, the sub-structure response is large due to the limited lateral stiffness of the vertical connection. But on the other hand, the motion of the sub-structure is also a manifestation of energy consumption. The more intense the relative motion between the sub-structure and the mega-structure, the better the energy dissipation. At the same time, there is a significant sudden enlargement of the top layer of the structure in the figure, considered as an effect of top edge sheath.

4. Conclusion
In this paper, the finite element analysis and structural model test method are used to calculate the dynamic characteristics and elastic time history of MSCSS with additional liquid viscous dampers and MFS. The test values are in good agreement with the calculated values, which is confirmed that the vibration test can greatly restore the seismic performance of the prototype structure under seismic loading. At the same time, it is concluded that the MSCSS with liquid viscous damper has superior seismic performance. With the change of the sub-structure position assembled the additional liquid viscous damper, the structural dynamic characteristics also change significantly, which can be basically determined. As the height of the sub-structure of the additional liquid viscous damper increases, the overall seismic performance of the building structure increases significantly.

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