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VERIFY TUNEDMASS DAMPER EFFECT OF THE PLATFORM SHED CONSTRUCTED ON RAILWAY VIADUCT

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ABSTRACT

The Platform Shed built on the Railway Viaduct is very small in weight compared to Railway Viaduct. Therefore, there is concern that the inertial force acting on Platform Shed will greatly amplify at the time of earthquake. Even in the Great East Japan Earthquake of 2011, damage was caused in Platform Shed which is built on the many Railway Viaducts. From this, it was necessary to improve the earthquake resistance of the Platform Shed. Generally, as a way to improve the earthquake resistance of buildings, there is a method of installing braces or earthquake resistant walls between the pillars or reinforcing the column pillars. However, in Platform Shed it is difficult to provide braces, load bearing walls, etc. due to the flow of passengers at platform and the problem of visibility of signs and bulletin boards. Therefore, focusing on reducing earthquake response by TMD (Tuned Mass Damper), we examined a method to improve the earthquake resistance of Platform Shed by installing TMD at the top of Platform Shed. In past studies, the effect of TMD in one mass point has been confirmed. Therefore, the effect of TMD in the case of a two mass system model with a large mass difference like Platform Shed built on the Railway Viaduct was verified analytically. As a result, regarding Platform Shed of this time, there is a possibility that Platform Shed response can be effectively reduced if TMD is optimally tuned with respect to the natural period of Railway Viaduct, regardless of the nonlinearity of the structure and input earthquake wave.

Keywords: Railway Viaduct;Platform Shed; Tuned Mass Damper

1. INTRODUCTION

The station building is a building used by many unspecified many passenger. At the station's platform like this, we call the roof installed at the top of the platform a Platform Shed. Depending on the location conditions, the type of Platform Shed is also divided into two, Platform Shed on the ground and Platform Shed built on Railway Viaduct. The latter is established in the station building in the Railway Viaduct section. It consists of Railway Viaduct which receives the train load directly as shown in Fig. 1 and Platform Shed which is provided thereon. This time, I focused on Platform Shed that is constructed on Railway Viaduct that has suffered many damage even in the Great East Japan Earthquake of 2011. In order to improve the earthquake resistance of such a structure, it is necessary to adopt a reinforcement method that does not hinder train operation and flow of passenger.Furthermore, it must be constructed while keeping the station function even during the construction period. For these reasons, there are many problems such as construction restrictions and working time. Therefore, as a method of solving these problems and improving the seismic resistance of Platform Shed, we focused attention on response reduction by TMD (Tuned Mass Damper). If you simply set up TMD on the top of Platform Shed, you can easily do the construction without disturbing train run and flow of passenger. Regarding TMD, the effect of 1 mass system in the past study 1) has been confirmed.

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However, no research has been done on a two-mass system having a large mass difference such as a Platform Shed constructed on Railway Viaduct like this time.

In this research, we verify analytically the response reduction effect of Platform Shed by TMD in a two mass system model with mass significantly different like Railway Viaduct and Platform Shed.

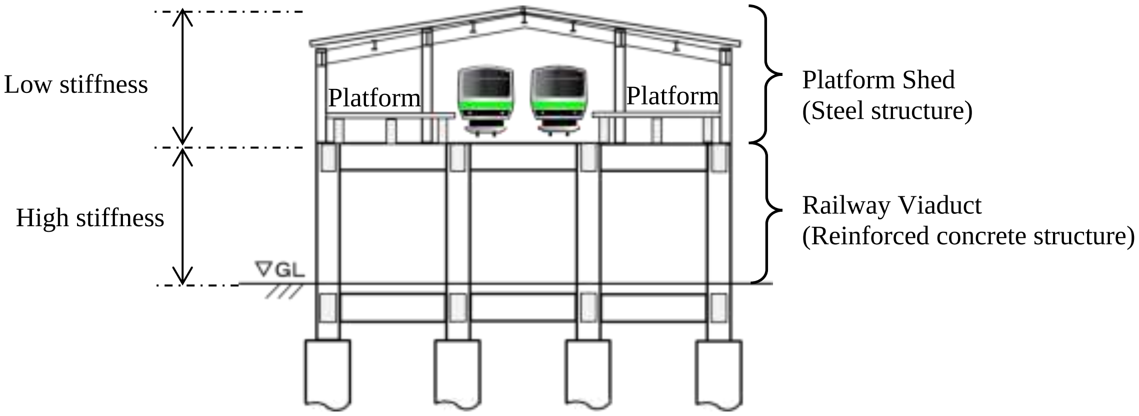


Figure 1. Platform Shed constructed on Railway Viaduct

2. CHARACTERISTICS OF THE PLATFORM SHED CONSTRUCTED ON RAILWAY VIADUCT

In the structures of Railway Viaduct and Platform Shed, Railway Viaduct is a reinforced concrete structure and Platform Shed is a steel structure. Many of the elevated Railway Viaducts built in the station building have a moment frame structure. Since the Railway Viaduct is an important structure directly receiving the load of the railway, members such as column beams have a large cross section. Therefore, the weight of the Railway Viaduct becomes very heavy. On the other hand, Platform Shed is a moment frame structure of steel frame making and it is very light compared with Railway Viaduct. Therefore, the difference in mass increases between Railway Viaduct and Platform Shed, and the seismic force acting on Platform Shed may be amplified. Also, if the natural period of Railway Viaduct and Platform Shed is close, the seismic force may increase due to the resonance of Platform Shed earthquake response.

From the above, Platform Shed that is constructed on Railway Viaduct has the following features.

(1) The difference in mass between Railway Viaduct and Platform Shed is large.

(2) Railway Viaduct and Platform Shed greatly differ in stiffness.

(3) The seismic force acting on Platform Shed is affected by Railway Viaduct.

3. ANALYSIS OUTLINE

As shown in Fig. 1, Railway Viaduct is a reinforced concrete structure with 3 spans in the direction perpendicular to the trajectory and 3 spans in the parallel direction. Platform Shed is a structure built on it. Each specification assumes a standard structure, as shown in Table 1. The analysis model is 2 mass models in which Railway Viaduct and Platform Shed are replaced by one mass point, and when attaching TMD on Platform Shed, it is assumed to be a 3 mass model. The mass of TMD was 5 to 70% of Platform Shed. Regarding the optimum tuning and optimum damping of TMD, the equations (1) to (3) are used from the past research. Regarding the set frequency of TMD, the case of optimum tuning for the natural frequency of Railway Viaduct and the case of optimum tuning for the natural frequency of Platform Shed are compared. Here, the former is defined as "Railway Viaduct optimum tuning", and the latter is defined as "Platform Shed optimum tuning". Also,as shown in (4),the ratio of the natural periods of Railway Viaduct and Platform Shed is taken as the natural period ratio (Ts / Tv).

Optimum tuning: $f_d = \frac{1}{1+\mu} \cdot f$ (1)

Optimum damping: $h_d = \sqrt{\frac{3\mu}{8(1+\mu)}}$ (2)

f : Any of the following natural frequencies

$\begin{pmatrix} f_s\text{ : Platform Shed natural frequency} \\ f_v\text{ : Railway Viaduct natural frequency} \end{pmatrix}$

Mass ratio: $\mu = m_d/m_s$ (3)

$\begin{pmatrix} m_d\text{ : TMD mass} \\ m_s\text{ : Platform Shed mass} \end{pmatrix}$

Natural period ratio: T_s/T_v (4)

$\begin{pmatrix} T_s\text{ : Platform Shed natural period} \\ T_v\text{ : Railway Viaduct natural period} \end{pmatrix}$

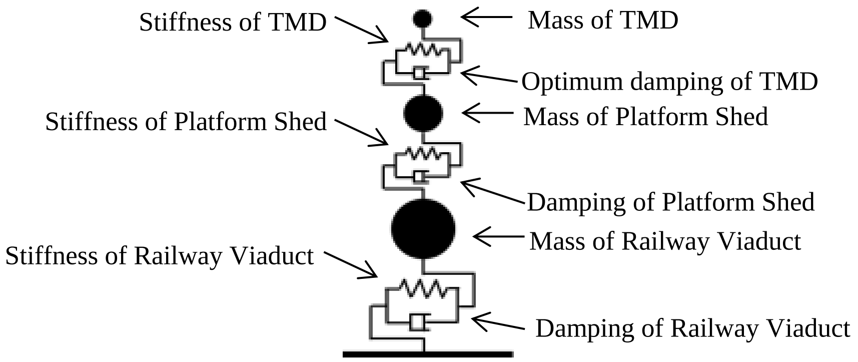


Figure 2.Analysis model

Table 1. Analysis conditions.

	Mass(kN)	**Natural period (s)**	**Stiffness (kN/m)**	**Damping constant**
Platform Shed	338.6	0.4	8,525	0.02
Railway Viaduct	6771.8	0.8	42,624	0.10

The analysis method is time history response analysis, and examines both cases where the restoring force characteristic of the structure is linear and nonlinear. The input earthquake ground motion uses a large earthquake occurring once every several hundred years (hereinafter extremely rare earthquake motion). The acceleration response spectrum is shown in fig 3.

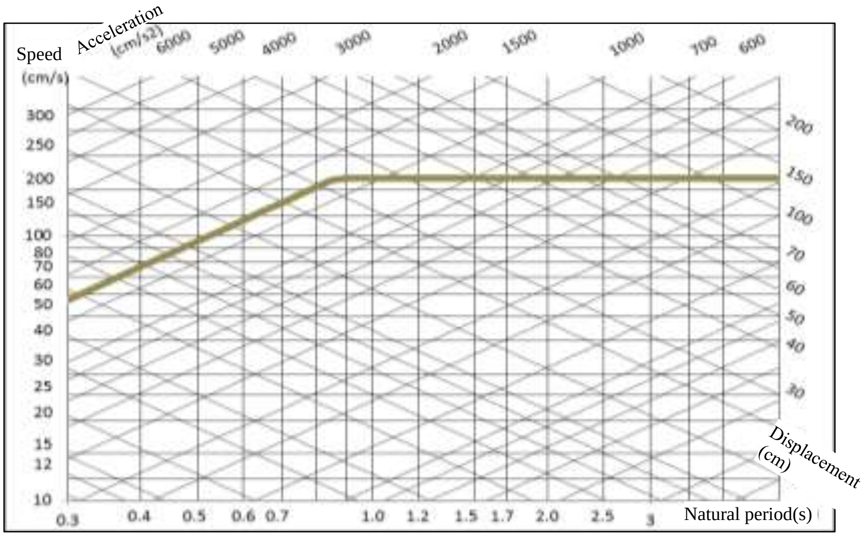


Figure 3. Input ground motions used for analysis

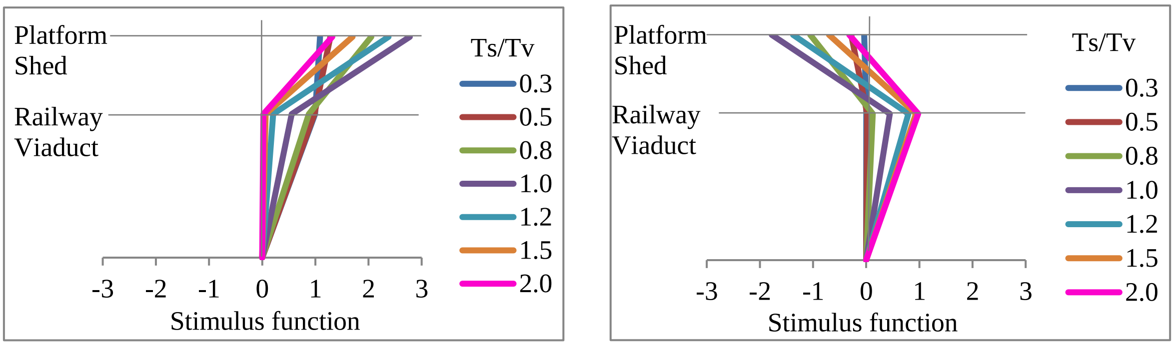
4. ELASTIC RESPONSE ANALYSIS

4.1 Eigenvalue analysis

First, in order to grasp the vibration characteristics of Railway Viaduct and Platform Shed, eigenvalue analysis was performed by changing the Ts / Tv to 0.3 to 2.0 by using a two mass system model of Railway Viaduct and Platform Shed. Table 2 shows the natural period in each mode. As the natural period ratio increases, the primary natural period gradually increases from 0.82 seconds to 1.61 seconds. Fig. 4 shows the stimulation function diagram in each mode. In the range of Ts / Tv ≦ 0.8, the primary is Railway Viaduct and the secondary is Platform Shed mode, and Railway Viaduct becomes dominant.

Table 2. Natural period by eigenvalue analysis.

Ts/Tv	**0.3**		**0.5**		**0.8**		**1.0**		**1.2**		**1.5**		**2.0**	
Mode	1st	2st	1st	2st	1st	2st	1st	2st	1st	2st	1st	2st	1st	2st
Natural period (s)	0.82	0.23	0.83	0.39	0.85	0.61	0.89	0.72	1.00	0.76	1.22	0.78	1.61	0.79



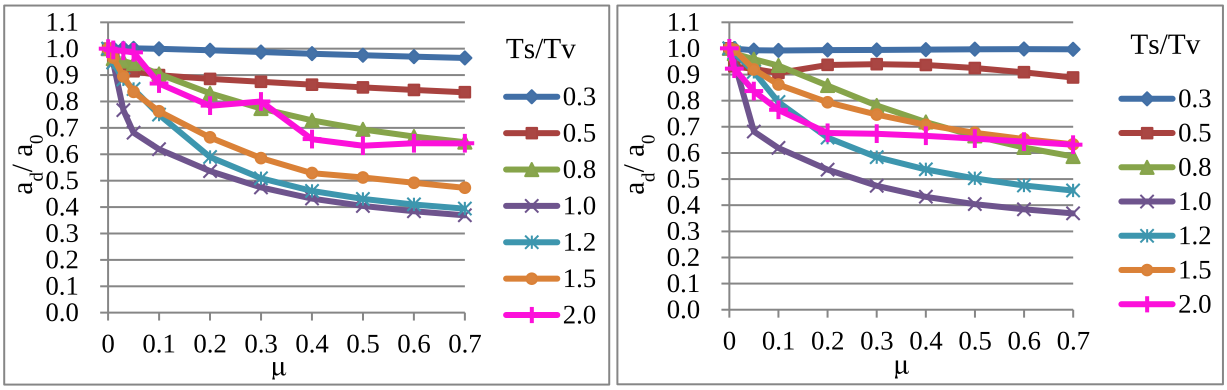
Primary mode

Secondary mode

Figure 4. Eigenvalue analysis result

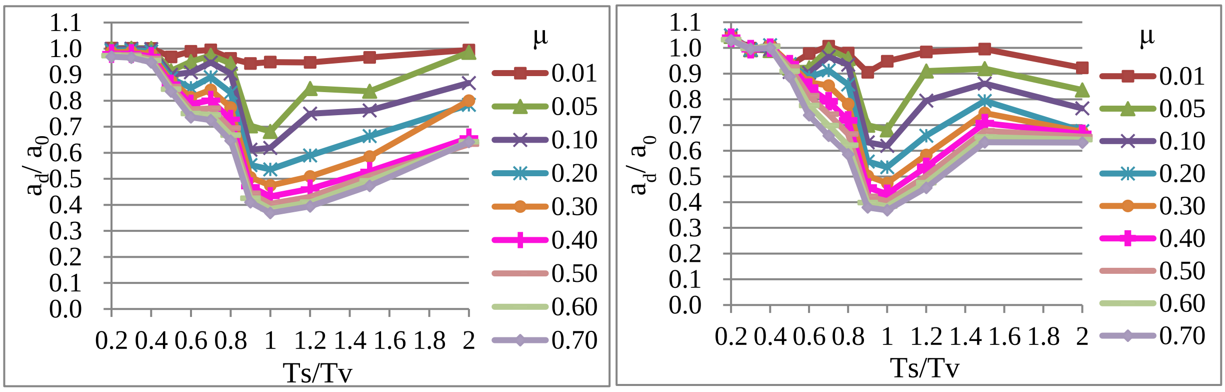
4.2 Optimal tuning of TMD

Next, as shown in Fig. 2, the effects of Railway Viaduct optimum tuning and Platform Shed optimum tuning were compared and examined using a three mass system model including TMD. In addition, we investigated the influence of the change of combination of natural period in each case. For the combination of natural periods, the natural period of Railway Viaduct (Tv =0.8 s) was fixed and Ts / Tv of Railway Viaduct and Platform Shed was varied from 0.2 to 2.0. The vertical axis in the following figures shows the reduction rate (a_d / a_0) of the maximum response acceleration (a_d) of Platform Shed in each case to the maximum response acceleration (a_0) of Platform Shed when TMD is not set up. The analysis result shows the relationship between (a_d / a_0) and μ in the case of "Railway Viaduct optimum tuning" and "Platform Shed optimum tuning" in FIG. 5. Fig. 6 shows the relationship between (a_d / a_0) and Ts / Tv in the case of highly "Railway Viaduct optimum tuning" and "Platform Shed optimum tuning". From the two figures, it is clear that the reduction rate is small when the natural period ratio is small. When Ts / Tv is small, the vibration mode of Railway Viaduct is dominant as can be seen from eigenvalue analysis. This is close to a state in which the rigidity of Platform Shed is large and Railway Viaduct and Platform Shed are integrally oscillating. On the other hand, when Ts / Tv is large, the rigidity of Platform Shed decreases and the influence of the mode oscillating independently increases, so it can be inferred that the effect of TMD increases. Also, as the natural period ratio approaches 1.0, resonance occurs and the response value increases. In comparison between Railway Viaduct optimum tuning and Platform Shed optimum tuning, in both cases the reduction rate increases as the mass ratio increases. When Ts / Tv is 0.3 or 0.5, it can be seen that Railway Viaduct optimum tuning has a larger reduction effect.



Railway Viaduct optimum tuning Platform Shed optimum tuning

Figure 5. Relationship between (a_d / a_0) and μ



Railway Viaduct optimum tuning Platform Shed optimum tuning

Figure 6. Relationship between (a_d / a_0) and Ts / Tv

4.3 Aggregate to equivalent 1 mass point

Next, the two-mass system model of Railway Viaduct and Platform Shed used in the study of the preceding paragraph was integrated into one equivalent mass point, and the equivalent natural period according to the combination was obtained. Equivalent natural period was obtained by using equations (5) - (7). Here, mi in the equation (5) is the mass of Railway Viaduct and Platform Shed, and δsi in the equation of (6) is displacement of Railway Viaduct and Platform Shed when the shear force acting on Railway Viaduct is the maximum. The results are shown in Table 3. The equivalent natural period shows a relatively large value around Ts / Tv = 1.0, but both are approximate to Railway Viaduct. From this, it is understood that Platform Shed does not greatly influence the vibration characteristic of Railway Viaduct in the range of the combination studied here.

Effective mass：$M=\frac{(\Sigma mi\cdot\delta si)^2}{\Sigma mi\cdot\delta si^2}$ (5)

Representative displacement：$\Delta=\frac{\Sigma mi\cdot\delta si^2}{\Sigma mi\cdot\delta si}$ (6)

Natural period：$T=2\cdot\pi\sqrt{\frac{M\cdot\Delta}{Q}}$ (7)

Table 3. Equivalent natural period.

Ts/Tv	**0.3**	**0.5**	**0.8**	**1.0**	**1.2**	**1.5**	**2.0**
Effective mass(M)	0.73	0.73	0.71	0.61	0.73	0.64	0.70
Representative displacement(Δ)	11.65	11.63	11.56	11.69	11.04	12.69	12.22
Equivalent natural period(T)	0.819	0.823	0.834	0.861	0.818	0.784	0.798

5. ELASTIC-PLASTIC ANALYSIS

In chapter 4, we examined the response characteristics of Platform Shed built on Railway Viaduct in the elastic range by changing the combination of Railway Viaduct and Platform Shed. In this chapter, under the same analysis conditions as Table 1, we examine the effect of TMD in considering plasticization, respectively.

5.1 Outline of elasto-plastic analysis

The analysis model is based on the three mass system model shown in Fig 2. For the restoring force characteristics of Platform Shed, the values in Table 1 are used for the initial stiffness, and the bilinear type is adopted as the maximum proof stress with an story drift angle of 1/100. For Railway Viaduct, it was modeled as a trilinear type in which the equivalent stiffness at the second break point matches the values in Table 1. The respective restoring force characteristics are shown in FIG. 7. The input earthquake ground motion is the same extremely rare earthquake motion as elastic response analysis.

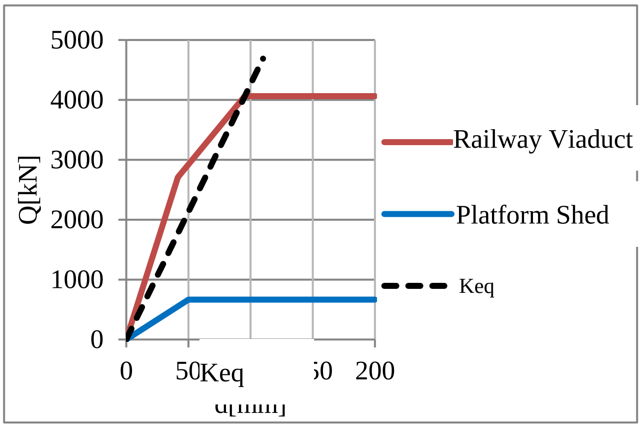


Figure 7. Restoring force characteristics of structure

5.2 Study of optimum tuning of TMD

On optimal tuning of TMD, we compared Railway Viaduct optimum tuning and Platform Shed optimum tuning. The results are shown in FIG.8. In both cases, as in the elastic response analysis, it can be seen that the reduction effect increases as the mass ratio increases. Also, except for some cases, the response reduction effect tends to be larger for Railway Viaduct optimum tuning.

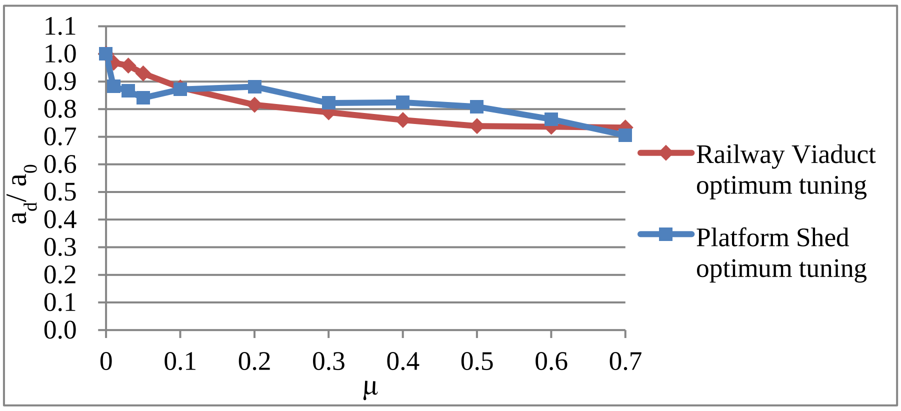


Figure 8. Comparison of optimal tuning

5.3 Impact of differences in input earthquake ground motions

Since the reduction effect of Railway Viaduct optimum tuning was generally large in the previous section, we examined the effect of TMD due to the difference in input earthquake ground motion as Railway Viaduct optimum tuning. For the input seismic motion used for the study, we use the four types of observed seismic waves normalized to 50 kine. It is shown in Table 4 and FIG.9.

Table 4. Earthquake ground motion.

Symbol	**Earthquake ground motion**	**Duration**	**Normalisation maximum acceleration**
EL	El Centro NS 1940	53.7(s)	510(gal)
TF	Taft EW 1952	54.4(s)	497(gal)
HC	Hachinohe NS 1968	51.0(s)	330(gal)
KB	JMA Kobe NS 1995	40.0(s)	425(gal)

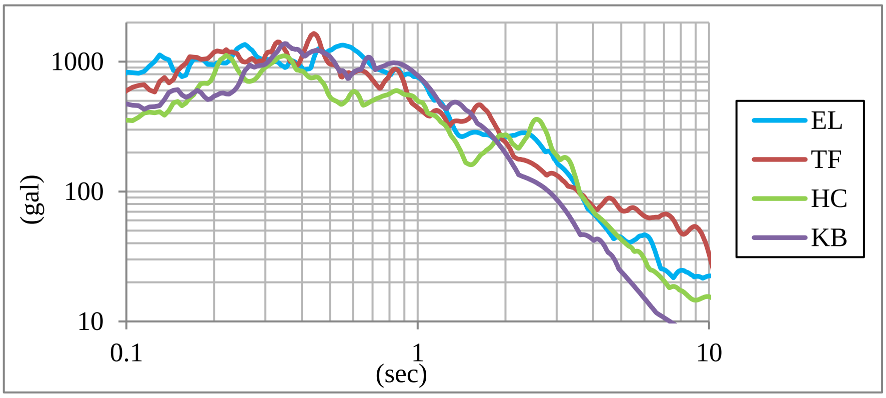


Figure 9. Acceleration response spectrum

The analysis results are shown in Fig.10. ER in the figure shows extremely rare earthquake motion. It was found that the reduction rate increases as the mass ratio increases in any seismic motion as with the extremely rare earthquake ground motion. Although there is a difference in effect depending on the input earthquake motion, it can be confirmed that the response acceleration of Platform Shed by TMD is reduced. ER in FIG. 10 indicates extremely rare earthquake ground motion.

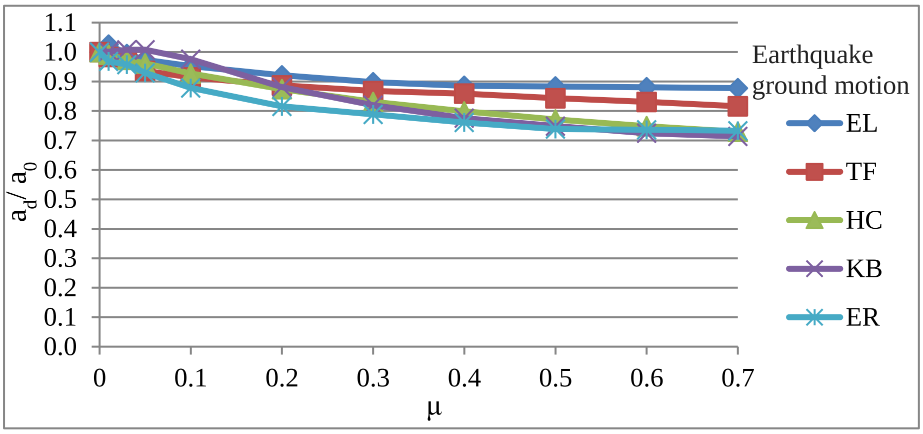


Figure 10. Comparison of response reduction rate due to difference in input ground motions

5.4 Consideration by the largest earthquake motion

The state of the structure at the time of inputting extremely rare earthquake ground motion was estimated from the maximum response value. Railway Viaduct has not reached the yield, but it is in a state where rigidity deterioration appears due to cracks. On the other hand, Platform Shed is within the elastic range, and nonlinearity does not appear markedly at the extremely rare earthquake motion input level. Therefore, we analyzed by inputting even larger seismic motion and confirmed the reduction effect by TMD when Railway Viaduct and Platform Shed reach the plastic region. Larger earthquake ground motion is the largest earthquake ground motion (hereinafter referred to as largest earthquake) considered at the construction site. The acceleration response spectrum is shown in FIG.11. The results of the analysis are shown in FIG.12. Here, we use displacement response to evaluate the properties in the nonlinear region where rigidity greatly decreases. The vertical axis of Fig. 12 shows the reduction rate (d_d / d_0) of the maximum response displacement (d_d) of Platform Shed in each case to the maximum response displacement (d_0) of Platform Shed when TMD is not set. There is a tendency that response reduction is reduced due to plasticization of Platform Shed. It can be seen that response reduction effect cannot be expected except when TMD with large mass ratio as Platform Shed optimum tuning is installed.

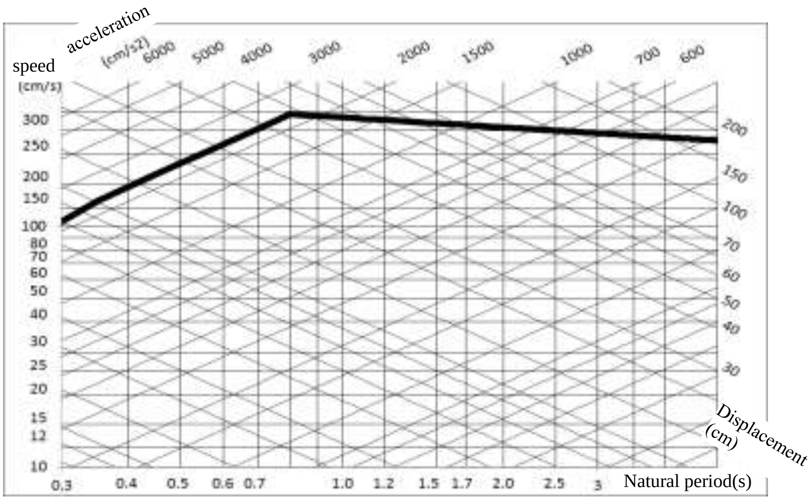


Figure 11. Acceleration Response spectrum

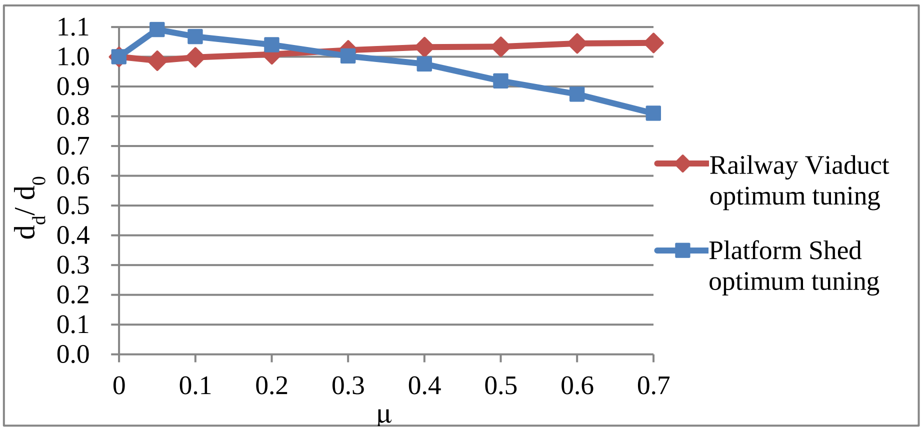


Figure 12. Influence of the largest earthquake motion

6. CONCLUSIONS

We verified the response reduction effect of Platform Shed by TMD in a two mass system model with mass significantly different like Railway Viaduct and Platform Shed. First, in the elastic response analysis, analysis was performed with various natural period cycle combinations. As a result, it was found that when Ts / Tv is small, the reduction rate is smaller than when it is large, and it does not function effectively in all natural periods. In addition, when comparing the case of Railway Viaduct optimum tuning and the case of Platform Shed optimum tuning, roughly Railway Viaduct optimum tuning has a larger reduction effect, but no significant difference was found. The same can be said for the case of considering the nonlinearity of the structure at the extremely rare earthquake ground motion level. And, when the input seismic ground motion changed, the effect of TMD could be confirmed although there was a difference in reduction effect depending on the type of wave. On the other hand, at the time of largest earthquake that the platform shed markedly plasticized, clear effective response reduction by TMD could not be confirmed except for some cases. From this, it is necessary to investigate the method for reducing the response of the structure in the case where the vibration property changes greatly due to plasticization.

7. REFERENCES

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