SEISMIC DESING OF RAILWAY STRUCTURES USING AASHTO HARMONIZED WITH JAPANESE RAILWAY SEISMIC DESIGN STANDARD

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1. INTRODUCTION

The North South Commuter Railway, a 38km long railway line, will be an elevated railway system in Metro Manila, Philippines. The Philippines is located in an earthquake-prone region, therefore it was imperative for the team of engineers to conduct a thorough seismic design to ensure safety during operations and resiliency against earthquakes. The design was based on AASHTO LRFD 2012, verified and modified with the Japanese Seismic Design for Railway Structures. This paper aims to introduce the differences between the seismic design considerations stipulated in AASHTO LRFD 2012 and the Japanese Design Standard for Railway Structures and Commentary (seismic design) revised in 2012, the harmonization between the two seismic design standards, and results of a hybrid seismic design.

2. JAPANESE SEISMIC DESIGN CONSIDERATIONS

In the Japanese and Philippine seismic design, earthquake resistant structures consider Level 1 and Level 2 earthquakes. Level 1 seismic accelerations are those expected to occur several times during the design life of the structure, limiting deformations and keeping the functionality of the structure during and after the earthquake. Level 2 seismic accelerations consider the most catastrophic seismic event that the structure might be subjected to, allowing larger damages limited to specific areas of the structure. On the other hand, AASHTO seismic design does not consider Level 1 or Level 2 seismic accelerations.

In seismic design, there are two seismic design principles, namely: (a) strength seismic design (Figure 1a) and (b) displacement seismic design (Figure 1b).

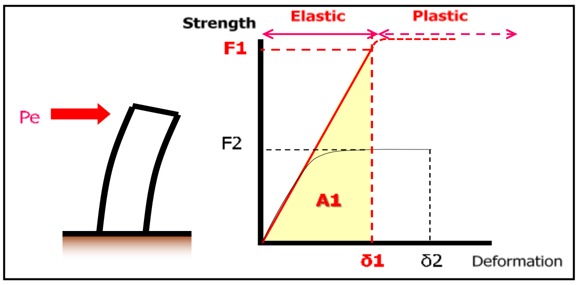


Figure 1. (a) Strength seismic design principle

In the strength seismic design principle (Figure 1a), structures are designed to absorb the seismic loadings using only the elastic (non-linear) region of the material (A1 of Figure 1). In this context, the yield strength of the structure will be determined by the strength seismic design principle.

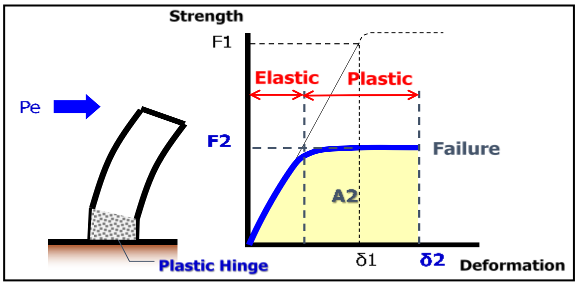


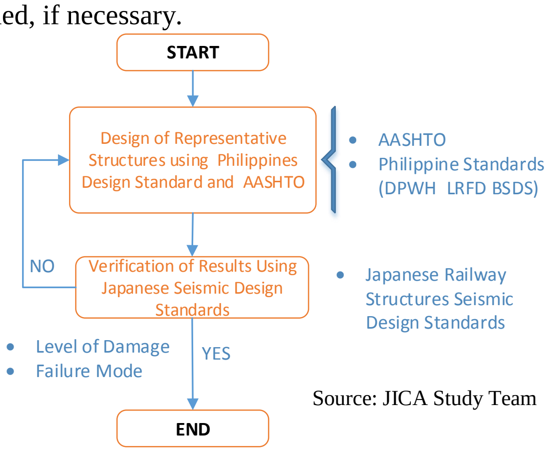
Figure 1. (b) Displacement seismic design principle

On the contrary, the seismic energy in the displacement seismic design principle (Figure 1b) is absorbed by a combination of both the elastic and plastic region of the material. Post-yielding, the energy is absorbed by the plastic region, allowing controlled damage at specific areas of the structure, called the plastic hinge.

In the seismic design of railway structures, it is also necessary to evaluate the vibration of the railway structure in order to avoid any derailments during seismic events. Namely, the natural period of the structure needs to be smaller than that of the rolling stock. This requirement is mentioned by Japanese seismic standard only.

3. DESIGN AND VERIFICATION APPROACH

The seismic design was initially conducted based on AASHTO which is widely used in the Philippines, implementing the seismic acceleration response coefficients specified in the DPWH-BSDS. In order to verify the seismic performance of the initial design (AASHTO), the results were compared to those obtained using the Japanese Design Standards for Railway Structures and Commentary (seismic design) revised 2012 (hereafter referred as JDSRS) and modified, if necessary.



Source: JICA Study Team

Figure 2. Seismic design and verification process

4.COMPARISSON OF DESIGN RESULTS

(a) Seismic design of piers

For normal soils, the seismic acceleration coefficient for specified in the DPWH-BSDS for Level 1 earthquakes is larger than that specified in JDSRS. However, for Level 2 earthquakes, the seismic acceleration coefficient stipulated in DSRS is more than twice larger than that specified in DPWH-BSDS. Table 1 shown the difference of the design acceleration coefficients of both standards.

Table 1. Comparison of Philippine and Japanese seismic design acceleration coefficients

Design Acceleration	DPWH-BSDS	JDSD
Level 1	0.5	0.4
Level 2	1.2	2.6

The difference between the seismic design accelerations reflects that the DPWH-BSDS considers that Level 1 earthquakes may occur several times during the design life of the structure. However, severe earthquakes (Level 2) are not considered to occur within the design life of the structure.

The verification results suggest that for Level 1 earthquakes, short piers located in hard soil and designed with DPWH-BSDS, it is not necessary to increase the dimension of the pier and number of transverse reinforcement since the yield strength meets the requirements. However, for Level 2 earthquakes, since JDSRS considers a larger seismic acceleration coefficient (Table 1), it is necessary to increase the number of longitudinal reinforcement, increasing the shear strength and ductility of the structure. As shown in Figure 3, the integration of DPWH-BSDS seismic design acceleration coefficient for Level 1 and JDSRS seismic acceleration coefficient for Level 2 results in higher yield strength, shear strength and ductility.

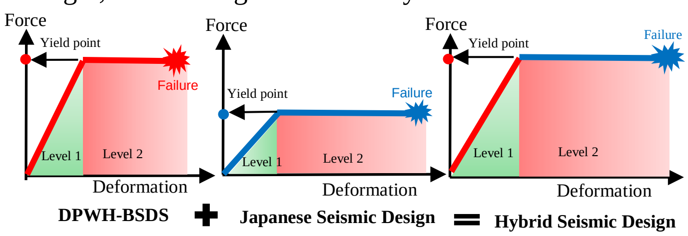


Figure3. Schematic Stress-strain curve (linear) of combining DPWH-BSDS and DSRS

On the other hand, tall piers located in soft soils, the natural period of the structure is longer. As shown in Figure 4, in AASHTO, the seismic coefficient is initially large at shorter natural periods, drastically decreasing as the period of the structure reaches a given value. On the contrary, for Level 1 earthquakes in JDSRS, the seismic coefficient is higher at longer structural periods. Therefore, the seismic design of tall piers located in soft soils was governed by JDSRS, considering the requirement of a larger seismic coefficient for structures with a longer natural period (Figure 5).

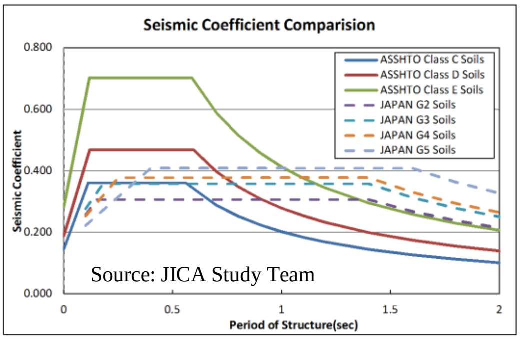


Figure 4. Comparison of seismic response spectrum of AASHTO and the Japanese Seismic Design code Level 1.

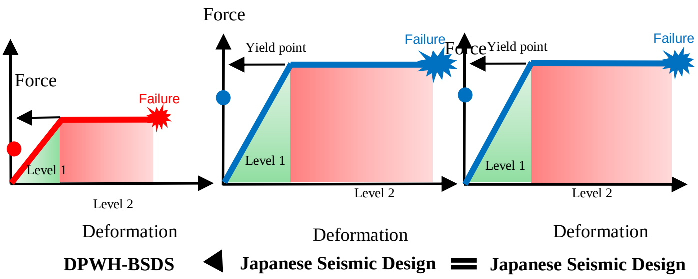


Figure 5. Schematic Stress-strain curve (linear)concept applied for tall piers located in soft soils

(b)Vibration Analysis

The deflection analysis was conducted in compliance with JDSRS using the preliminary results obtained from AASHTO showed that the deflection of the piers exceeded the allowable limits attributed to a lower soil spring of soft soils. In order to reduce the deflection of the piers it was necessary to increase the stiffness of the substructure and column.

5. CONCLUSIONS

The verification of the seismic design results of AASHTO didn't meet the limits specified in the Japanese Seismic Design specifications, especially for tall piers located in soft soils. The following countermeasures were taken when the preliminary design (AASHTO) did not meet the Japanese standards (JDSRS): 1) Increasing the volume of re-bars or change the pier shape when the pier seismic performance was insufficient, 2) increasing the rebar arrangement or pile number when the piles yielded before the pier, 3) modifying the arrangement of the piles when the deflection of the pier or structural period exceeded the allowable limits.

REFERENCES

1. Final Report the Detailed Design Study of the North-South Commuter Railway Project (Malolos- Tutuban) in the Republic of the Philippines, August 2017.