

INTRODUCTION TO DIRECT DISPLACEMENT-BASED DESIGN FOR SEISMIC DESIGN OF BRIDGES

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1. INTRODUCTION

Earthquakes occur all over the world, and they have caused significant damage to highway bridges. Based on the extensive damage, earthquake resistance technology for highway bridges has developed and continuously improved. Since the 1995 Kobe earthquake, the development and improvement of seismic design provisions in Japan, like Force-based design and Performance-based design, significantly reduced damage to highway bridges caused by earthquakes in recent years, such as in the 2011 Tohoku earthquake. Although less damage to the structures has been observed in recent earthquakes, there are still some issues to be improved.

Displacement-based design as a new design approach is introduced in the Bridge Manual by New Zealand Transport Agency. This approach allows the displacement demand to be directly calculated in the design process instead of being assumed by the displacement-based design. Priestly et al.[1, 2] have developed and proposed the Displacement-based design method where displacement is taken as the main parameter. Therefore, this paper introduces the Displacement-based design method as an alternative to the Force-based design method based on the work done by Priestly et al.[1, 2].

2. FORCE-BASED DESIGN

Force-based design, FBD, is based on calculating the base shear force resulting from the seismic vibration, which uses the acceleration response spectrum (ARS), as shown in Fig.1, which considers the elastic phase of the bridge structure. The design procedure uses the initial parameters of stiffness, natural period, and strength of the structure. In this process, the stiffness of the elements is assumed at the beginning to represent the structural response, followed by the calculation of the natural period, response acceleration, seismic force, and yield displacement of the structure.

3. ISSUES OF FBD

FBD method has been practiced for a long time, focusing on the seismic force. However, in recent years, problems associated with force-based design have been discussed in structural engineering for the construction of resilient structural systems. Some of the issues related to FBD are as follows:

- ① The initial stiffness of the member is unknown and therefore is assumed first based on the properties of structural members at the beginning of the design procedure before the seismic design force is calculated. This is because stiffness depends on the member's strength [1]. The calculated force is then distributed according to the assumed stiffness, which will be changed when the member dimension is changed.
- ② An elastic period is related to the stiffness. Therefore, the value of the calculated period will vary due to different stiffness assumptions.
- ③ The distribution of forces between structural members based on estimated stiffness is unreasonable and leads to concentrate strength in stiffer members, which could result in brittle failure.
- ④ Structural damage is evaluated from strain or drift. However, the relationship between force and damage to the structure is not clear.

Considering the various residing issues in the current FBD process, a new alternative method of the Displacement-based approach is proposed and being researched[1, 2].

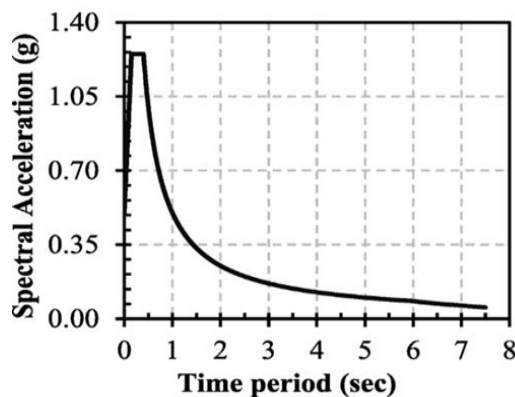


Fig. 1: Acceleration Response spectrum[1]

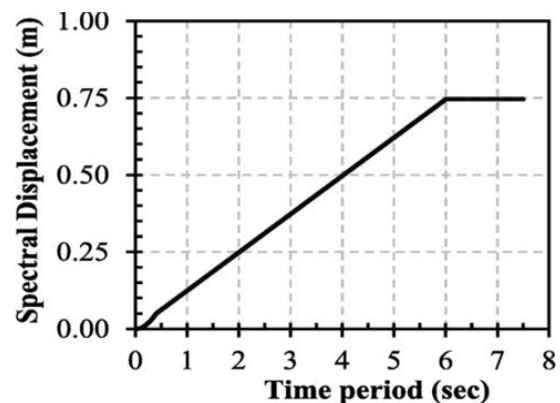


Fig. 2: Displacement Response spectrum[1]

4. DISPLACEMENT-BASED DESIGN

Displacement-based Design, DBD, is opposite to that of the FBD. DBD particularly emphasizes design displacement at an inelastic phase and ductility capacity with less focus on strength. This method uses the displacement response spectrum (DRS), as shown in Fig.2, and calculates the base shear force and moment capacity from the natural period. A new seismic design known as Direct displacement-based design (DDBD) is explained briefly in this paper. A basic concept of DDBD is shown in fig.3. DDBD, first introduced in 1993 by M.J.N Priestley, is a performance-based design approach in which performance levels are described in terms of displacements since displacement is a better indicator of damage than strength. The new method considers the inelastic phase of the structure, which gives the maximum target displacement and is characterized by the secant stiffness and equivalent viscous damping (EVD) of the single degree of freedom system, as shown in fig.3(a). The maximum target displacement is defined from material strain limits or the drift limits obtained from the design codes under the specific seismic load. The displacement-based design method begins with the target design displacement, which helps evaluate the limit state and is easy to understand in seismic design.

5. BASIC CONCEPT OF DDBD

DDBD approach mitigates the inherent shortcomings in the FBD procedure and analysis process. The fundamental problem of the FBD procedure is to estimate the initial stiffness of the member, and also accurate assumption cannot be made since the force generated due to earth vibration is unknown[1]. Therefore, DDBD has the primary objective of solving these problems with FBD and helping in the better performance of the seismic and safety structures.

The basic concept and steps carried out in the DDBD process are explained briefly below:

1. Maximum inelastic displacement (Δ_d)

Calculate using the yield displacement and the ductility.

$$\Delta_d = \mu \Delta_y$$

where μ is ductility and Δ_y yield displacement.

2. Equivalent viscous damping (ξ_{eff}) for concrete bridge

$$\xi_{eff} = 0.05 + 0.444 \left(\frac{\mu - 1}{\mu \pi} \right)$$

3. Effective period (T_{eff})

$$T_{eff} = T_c \times \frac{\Delta_d}{\Delta_c}$$

where T_c is the corner period, and Δ_c is the corner displacement.

4. Effective stiffness (K_{eff})

$$K_{eff} = 4\pi^2 \frac{W_s}{T_{eff}^2}$$

where W_s is an effective mass of the structure.

5. Base shear (V_b) and Moment Capacity (M_n)

$$V_b = K_{eff} \Delta_d$$

$$M_n = V_b H_e$$

where H_e is an effective height of the structure.

6. CONCLUSIONS

This paper briefly introduces the Direct Displacement-Based Design (DDBD) as an alternative to the Force-based design (FBD) and compares to the conventional FBD procedure. In the current practical seismic engineering of structures, FBD has been approved trustfully and is widely used worldwide. In contrast to FBD, target displacement is the input parameter in the DDBD procedure, which is a better indicator of damage than strength. The DDBD method can replace the FBD method, which helps to evaluate the limit.

REFERENCES

1. M.J.N. Priestley, G.M. Calvi, M.J. Kowalsky, 2007. IUSS Press: Displacement-Based Seismic Design of Structures.
2. Priestley M.J.N, Seible F and Calvi G M, 1996. Seismic Design and Retrofit of Bridges. John Wiley & Sons Inc
3. Mackie, K., Suarez, V., & Kwon, O. S. SEISMIC PERFORMANCE ASSESSMENT OF CONCRETE BRIDGES DESIGNED BY DISPLACEMENT-BASED METHOD

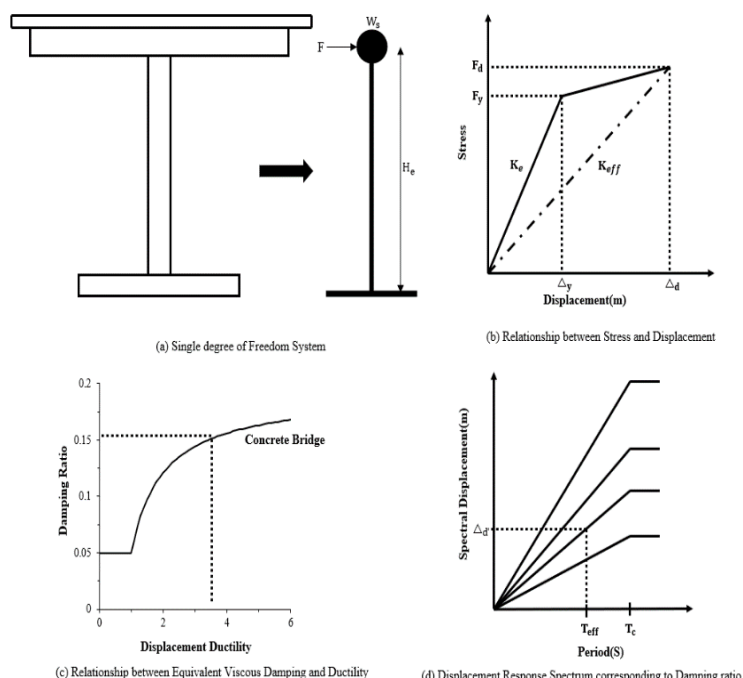


Fig. 3: Basic Concept of DDBD