Dynamic analysis for half-through steel arch bridge subjected to ground motion and fault displacement

Kumamoto University, GSST. Student Member. Evi Nur Cahya
Kumamoto University, GSST. Fellow Member. Toshitaka Yamao
Kumamoto University, GSST. Full Member. Akira Kasai

1. Introduction

It is still necessary to establish a method concerning the effect of fault displacement to check the seismic performance developed from nonlinear dynamic analysis for arch bridges design [3]. Furthermore, it is important to construct steel arch bridges possessing high seismic capacity at minimum cost. Half–through steel arch bridge is one of the arch bridges which reveal complicated behavior when subjected to ground motion or ground motion together with fault displacement. However, seismic performance and failure behavior for the half-through type arch bridge model have not been clarified yet and only few studies concerning nonlinear seismic analysis when subjected to fault displacement have been reported [2]. This paper presents the seismic behavior of the dynamic response analyses of a half-through steel arch bridge subjected to earthquake ground motion and fault displacement.

2. Theoretical arch model

The theoretical arch model studied herein is representative for actual half-through type arch bridges as shown in Fig.1, in which 11 vertical columns are hinged to arch ribs at both ends. The cross sectional profiles of vertical members and lateral members are rectangular and I-sections as shown in Fig. 2.

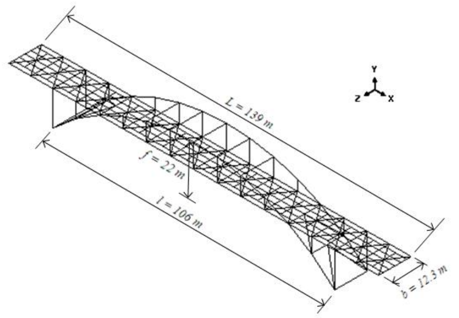
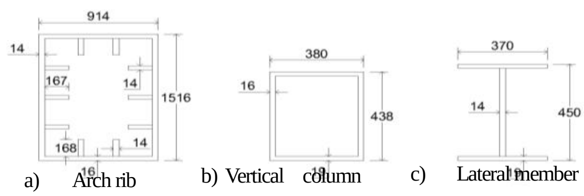


Fig. 1 Theoretical arch model



a) Arch rib b) Vertical column c) Lateral member

Fig. 2 Cross sectional profiles of members

The model was assumed to have no residual stresses and initial crookedness modes. Material properties of the model used in the numerical analyses were assumed to be SM490Y steel type (JIS) with the yield stress (σy) of 353 MPa and Young's modulus E was 206 GPa, respectively. The arch rise-to-span ratio (f/l) was taken to be 0.21 according to the condition of the actual arch bridges.

3. Input seismic waves

The fault displacement wave used in this analysis was obtained from the time integral of the acceleration response wave, that is, the ground motion simulated from 1999 Taiwan Jiji Earthquake wave. For the 1999 Taiwan Jiji Earthquake input wave, relative fault displacement measured after the earthquake was also concerned. There are three fault displacement waves are used in this analysis. The relative displacement curve for different two fault displacement waves and the maximum relative displacement wave is three meters. In dynamic response analysis, both the seismic waves and the fault displacement wave were input in order to simulate the movement at both ends of stiffened girder and at both arch springing.

4. Eigenvalue analysis

The eigenvalue analysis was carried out to investigate the effect of arch ribs and stiffened girders on the natural periods of the arch bridge model. In order to understand the fundamental dynamic characteristics, Table I presents the natural periods and the effective mass ratios of each predominant mode, from ABAQUS Software. The maximum effective mass ratios obtained in X, Y and Z directions imply the order of the dominant natural period.

Table 1 Results of eigenvalue analysis

Order of period	Natural Frequency (Hz)	Natural Periods (sec)	Effective mass ratio (%)		
			X	Y	Z
1	1.0341	0.9670	74	0	0
2	1.9767	0.5059	0	0	75
3	2.6452	0.3780	0	0	0
4	2.6452	0.3780	0	0	0
5	3.3823	0.2957	0	0	0
6	3.7199	0.2688	26	0	0
7	4.1054	0.2436	0	0	25
8	4.1988	0.2382	0	100	0
9	5.0428	0.1983	0	0	0
10	5.2847	0.1892	0	0	0

5. Response behavior of fault displacement

The dynamic analysis of the arch bridge model is conducted in direct integration analysis. In this analysis, the seismic waves were input in longitudinal and transverse

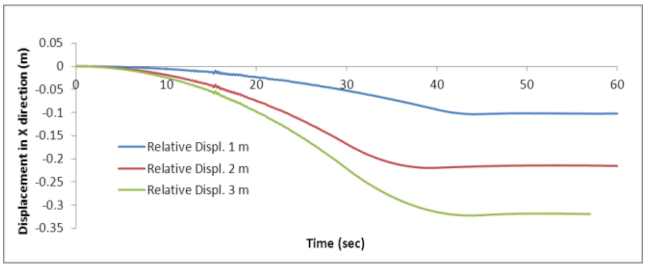


Fig. 3 Displacement-time history response in X-direction (for acceleration in longitudinal direction)

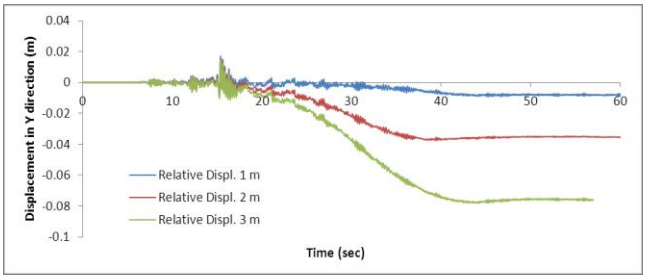


Fig. 4 Displacement-time history response in Y-direction (for acceleration in longitudinal direction)

direction, by ABAQUS software [4]. By using the acceleration data and fault displacement of Jiji Earthquake for longitudinal direction, with the damping ratio (h) = 0.03, the longitudinal displacement (X-direction) has been checked at the arch crown. Fig. 3 and Fig. 4 shows the displacement response obtained from the dynamic analysis in X-direction (in acceleration direction) and in Y-direction (in fault displacement direction). The dynamic analysis was also carried out in transversal direction in the same procedure. The transversal displacement (Z-direction) has been checked at the arch crown. Fig. 5 shows the displacement response obtained from the dynamic analysis in Z-direction (in acceleration direction).

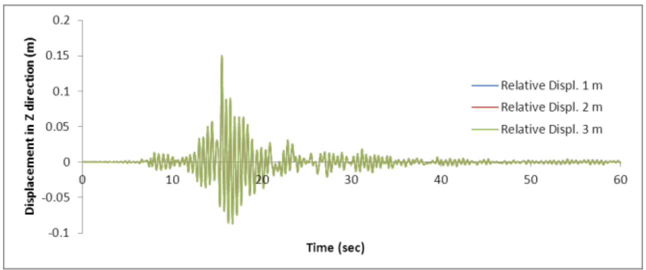
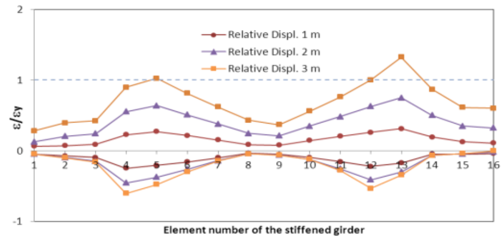
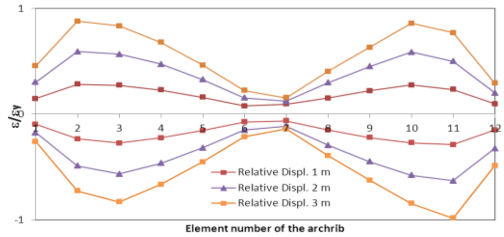


Fig. 5 Displacement-time history response in Z-direction (for acceleration in transversal direction)

Furthermore, it is also recognized that in this analysis, some of the stiffened girders reach yield for both loading in longitudinal direction and transversal direction. This is caused by the magnitude of the acceleration recorded from the earthquake. According to the analytical results, it was found that the plastic members were clustered near the intersections of arch ribs and stiffened girders. And this is caused by the large deformation at these intersection zones.



a) stiffened girder



b) arch rib

Fig. 6 The maximum and minimum plastic ratios $\varepsilon/\varepsilon_y$ of strains responses in the a) stiffened girder b) arch rib (for acceleration in longitudinal direction)

6. Conclusions

The seismic behavior of a half-through steel arch bridge subjected to ground motions in longitudinal and transversal directions were investigated by dynamic response analysis. There are two seismic waves according to JSHB seismic waves were simulated and discussed. The conclusions of this study are summarized as the following.

1) The effect of the fault displacement wave direction on the damage of the half-through steel arch bridge model is dominant.
2) The results obtained from dynamic analysis indicate that the plastic members are clustered near the joints of the arch ribs and the stiffened girders for longitudinal and transversal directions. This is caused by the large deformation at this intersection zones.
3) The maximum displacements taken from displacement response in longitudinal direction occur under earthquake wave in longitudinal direction. And the arch bridge model is judged to damage under the three meters relative displacement in this earthquake wave because the maximum stress in members reaches their yield stresses.

7. References

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[2] Yamao, T., Sho T., Murakami S. and Mazda T., "Seismic behavior and evaluation of seismic performance of half through steel arch bridges subjected to fault displacement", Journal of Seismic Engineering , pp.317-324, 2007.

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[4] Dassault Systèmes Simulia Corp., ABAQUS User's Manual, Version 6.11, 2011.