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zapobieganie diagnostyka naprawy rekonstrukcje

Prof. Masahiro SAKANO, *peg03032@nifty.com*
Kansai University, Osaka, Japan
Yuji NISHIGAKI, *one_life0617yuji@yahoo.co.jp*
Graduate School of Engineering, Kansai University, Osaka, Japan
Yorkio KAWAKAMI, *yoriko-kawakami@hanshin-exp.co.jp*
Hanshin Expressway Corporation

ELASTO-PLASTIC RESPONSE OF STEEL BRIDGE PIER BASE JOINT UNDER SEISMIC LOADING

SPRĘŻYSTO-PLASTYCZNA ODPOWIEDŹ POŁĄCZENIA PODSTAWY KONSTRUKCJI NOŚNEJ MOSTU STALOWEGO NA OBCIĄŻENIE SEJSMICZNE

Abstract In this study, the elasto-plastic response of a whole structure, including both superstructures and substructures, was estimated by means of dynamic elasto-plastic finite element analysis, and the elasto-plastic strain history at the top end of triangular ribs was estimated by means of static elasto-plastic finite element analysis using the results obtained by dynamic elasto-plastic finite element analysis. As a result, displacement response of the steel bridge pier can be estimated by means of dynamic elasto-plastic finite element analysis. The maximum displacement response δ_{max} is 207mm and the minimum displacement response δ_{min} is -291mm at the top of column in the case of a 0.03 damping coefficient. By means of static elasto-plastic finite element analysis, it was shown that there was a possibility that the maximum strain range ($\Delta\varepsilon_{ymax}$) can exceed 20% at the top end of triangular ribs.

Streszczenie W pracy analizowano sprężysto-plastyczne zachowanie się całej konstrukcji obejmującej przęsła oraz konstrukcję wsporczą za pomocą dynamicznej analizy metodą sprężysto-plastycznych elementów skończonych. Przebieg zmienności odkształceń sprężysto-plastycznych na górnym wierzchołku trójkątnego żebra szacowano za pomocą analizy statycznej z wykorzystaniem sprężysto-plastycznych elementów skończonych wykorzystując wyniki otrzymane z analizy dynamicznej metodą sprężysto-plastycznych elementów skończonych. W efekcie przemieszczenia stalowej konstrukcji wsporczej mostu mogły być oszacowane na podstawie analizy dynamicznej za pomocą sprężysto-plastycznych elementów skończonych. W przypadku współczynnika tłumienia 0,03 maksymalne przemieszczenie δmax wierzchołka filara wynosiło 207 mm, natomiast przemieszczenie minimalne δ_{min} było –291 mm. Wykorzystując statyczną analizę sprężysto-plastyczną metodą elementów skończonych wykazano, iż maksymalny zakres zmienności odkształceń $\Delta\xi_{ymax}$ górnego wierzchołka trójkątnych żeber może przekroczyć 20%.

1. Introduction

In the 1995 Hyogoken-Nanbu Earthquake, a rigid steel frame bridge pier was fractured at its base joint, as shown in Fig. 1. Cracks were developed at the top of triangular ribs between column and base plate, and connected one another. Eventually, more than a half section of the column failed[1)]. These cracks are presumed to have been initiated at the fillet weld toe on the column side near the top end of the triangular ribs, and propagated from the northwest corner to the northeast and southwest corners connecting each other. There is a possibility that

extremely low cycle fatigue cracks could be developed by excessive cyclic loading during the earthquake. In this study, the elasto-plastic response of the whole structure, including both superstructures and substructures, was estimated by means of dynamic elasto-plastic finite element analysis, and the elasto-plastic strain history at the top end of triangular ribs was estimated by means of static elasto-plastic finite element analysis using the results obtained through dynamic elasto-plastic finite element analysis.

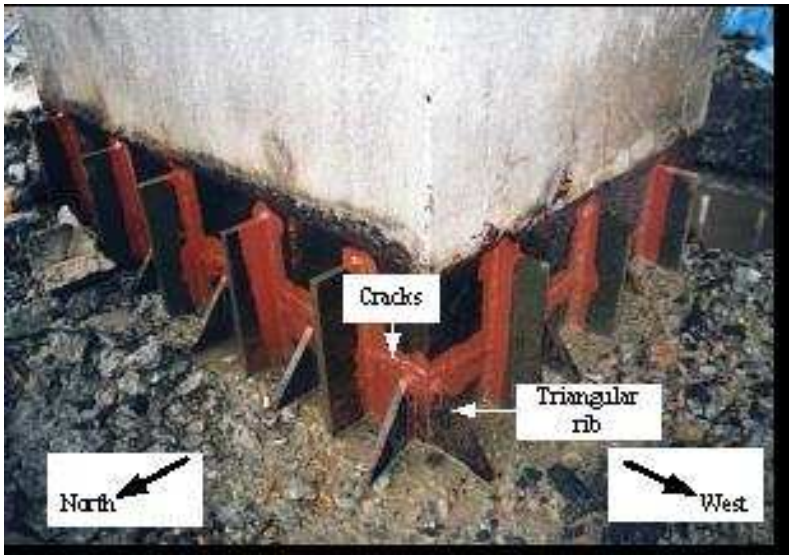

Fig. 1. Cracks connecting the top ends of triangular ribs

2. Elasto-Plastic Response of a Whole Steel Pier

2.1 Analytical Method

Fig. 2 shows the analyzed steel bridge pier and superstructures. Fig. 3 shows its analytical model. Dynamic elasto-plastic finite element analysis was conducted using a three-dimensional beam element. The large-mass method was applied in order to shake the ground directly using the seismic acceleration record (N-S direction) measured at the Osaka Gas Fukiai Plant during the Hyogoken-Nanbu Earthquake (see Fig. 4). The beam element was supposed to be a uniform box section, neglecting longitudinal and transverse stiffeners and filled concrete. Material properties were supposed as follows;

Young's modulus: 200GPa
Poisson's ratio: 0.3
Unit mass of steel: 7850kg/m^3
Yield stress: 235MPa
The damping coefficient: 0.03 and 0.05

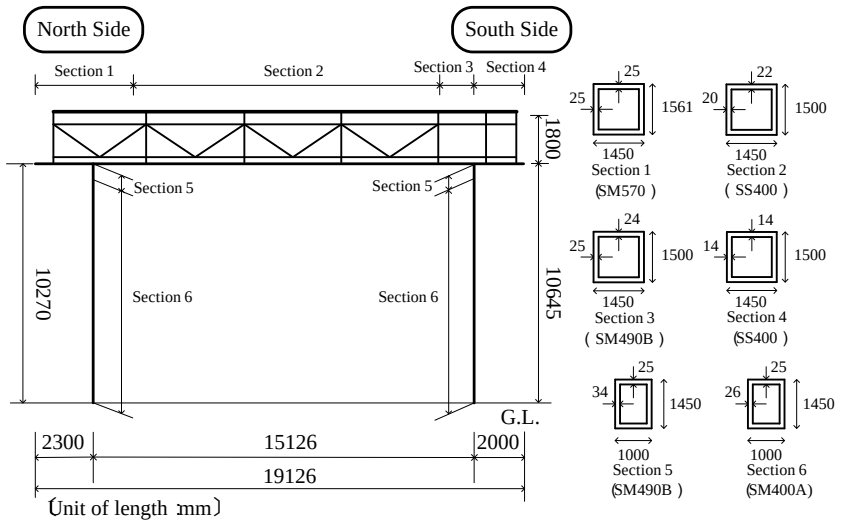

Fig. 2. Analyzed steel bridge pier and superstructures

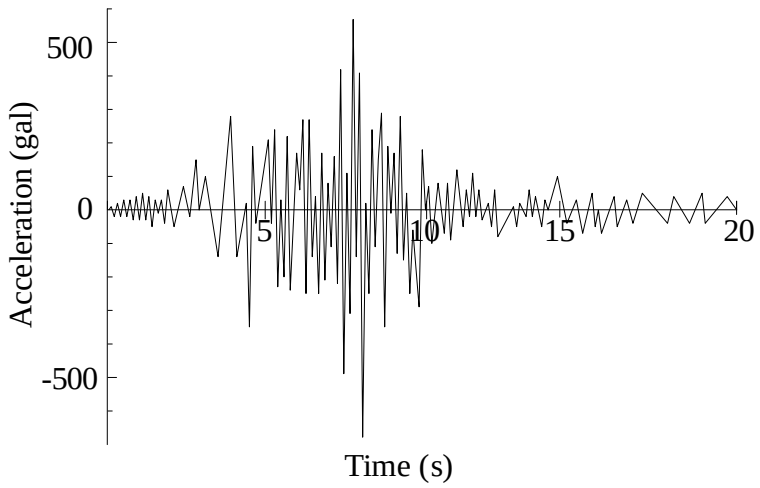

Fig. 3. Analytical model of the steel pier and superstructures

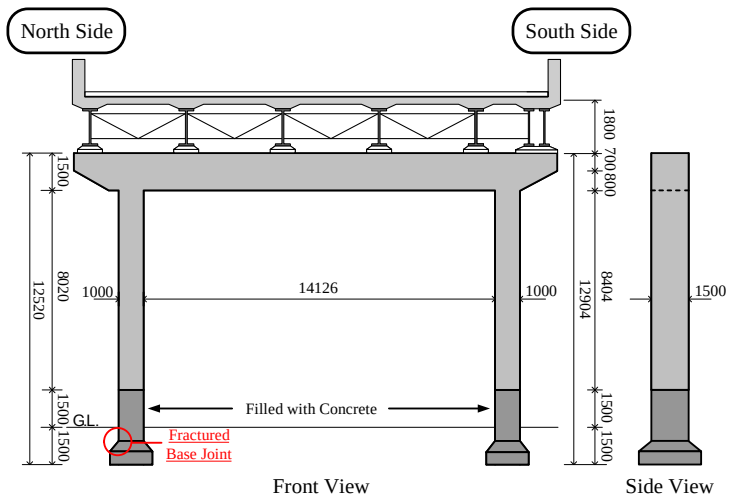

Fig. 4. Seismic acceleration record of N-S direction at the Osaka Gas Fukiai Plant

2.2 Analytical Results

Fig. 5 shows displacement response at the top of the north column. The horizontal axis represents time t (s), and vertical axis represents relative displacement of the north column top to its bottom. Solid and broken lines show the displacement response in cases of damping coefficients 0.03 and 0.05, respectively. The maximum displacement response δ_{max} is 207mm and the minimum displacement response δ_{min} is -291mm in the case of a 0.03 damping coefficient, while δ_{max} is 155mm and δ_{min} is -233mm in the case of a 0.05 damping coefficient.

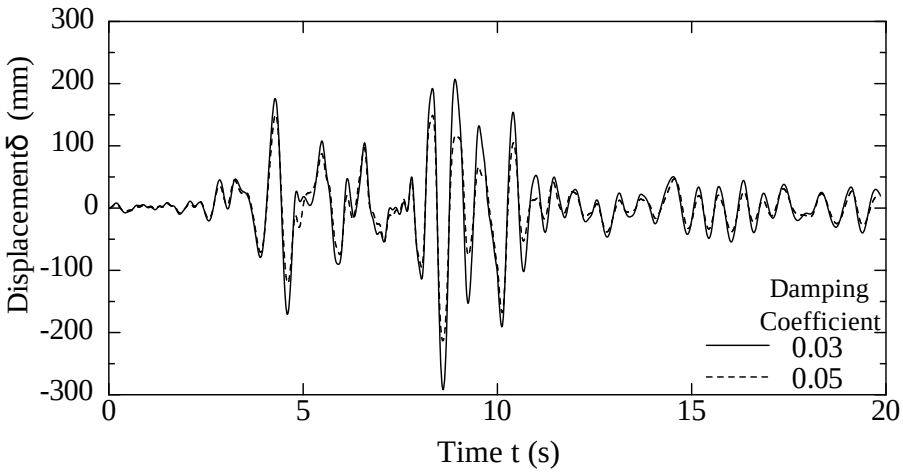

Fig. 5. Displacement response at the top of the north column

3. Elasto-plastic Strain History of Steel Pier Base Joint with Triangular Ribs

3.1 Analytical Method

Fig. 6 shows an analytical model for the static analysis. Static elasto-plastic finite element analysis was conducted using three-dimensional shell elements for the north column where cracks were detected, and three-dimensional beam elements for the other beam and column members. Fig. 7 shows the cyclic stress-strain curve[2)] used in the static analysis. The base plate at the bottom end of the column was completely restrained. The displacement obtained in the dynamic elasto-plastic analysis was applied to the top of the column, and then elasto-plastic strain history at the top end of the triangular ribs was estimated.

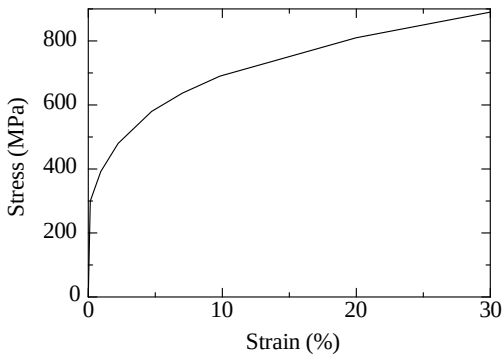

Fig. 6. Analytical model for static elasto-plastic finite element

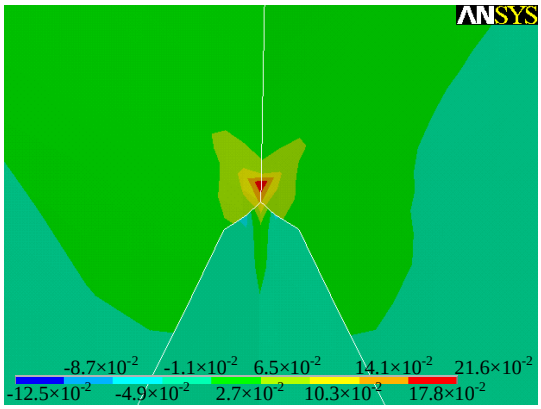

Fig. 7. Cyclic Stress-Strain curve used in the static elasto-plastic analysis

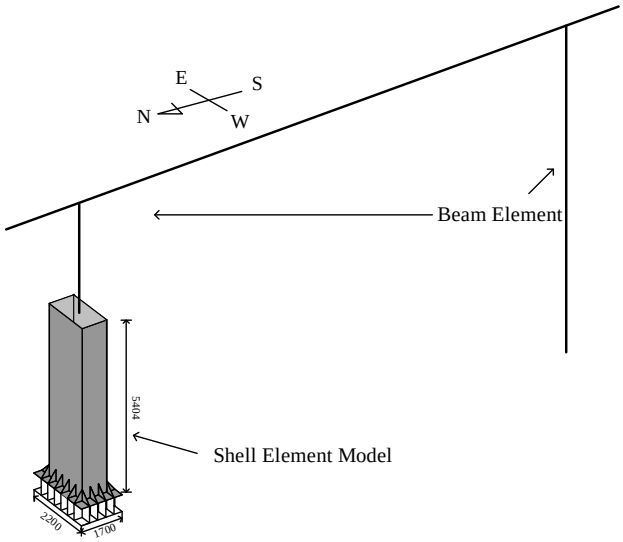

Fig. 8. Longitudinal strain distribution near the top end of the triangular ribs

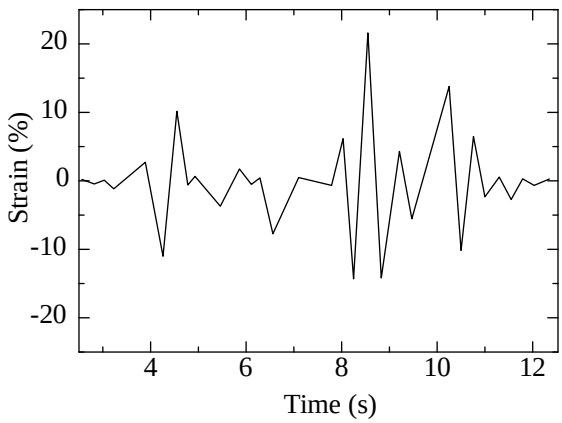

Fig. 9. Strain history at the top of the northwest triangular rib

3.2 Analytical Results

Fig. 8 shows a longitudinal strain distribution near the top of the northwest triangular ribs. Remarkable strain concentration is observed at the top end of the triangular ribs, as shown in Fig. 8. Fig. 9 shows strain history at the top of the triangular ribs in the northwest corner. The maximum value of tensile strain is 21.6 % and the minimum value of compressive strain is -14.3% in the case of a 0.03 damping coefficient.

4. Conclusions

The principal results obtained through this study are as follows

(1) Displacement response of the steel bridge pier can be estimated by means of dynamic elasto-plastic finite element analysis. The maximum displacement response δ_{max} is 207mm and the minimum displacement response δ_{min} is -291mm at the top of column in the case of a 0.03 damping coefficient.

(2) By means of static elasto-plastic finite element analysis, it was shown that there was a possibility that the maximum strain range ($\Delta\varepsilon_{ymax}$) can exceed 20% at the top end of the triangular ribs.

5. References

1. Hanshin Expressway Maintenance Technology Center: Research Report on the Plastic Deformation Capacity of Steel Piers, 1995. (in Japanese)
2. T. Nishimura and C. Miki: Strain-controlled Low Cycle Fatigue Behavior of Structural Steels, Proc. of JSCE, Vol.279, pp.29-44, 1978. (in Japanese)