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NUMERICAL STUDY ON FAILURE PROCESS AND ULTIMATE STATE OF STEEL BEARING UNDER COMBINED LOAD

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1. INTRODUCTION

On April 16, 2016 Kumamoto earthquake caused various damage of bridge and related components. A lot of steel bearings are damaged by the earthquake, which affect functionality of the entire bridge. It is important to understand failure process and ultimate state of steel bearing in detail. Since the 1995 Southern Hyogo Prefecture Earthquake, several studies about the ultimate state of steel bearing during the earthquake were carried out. However, there are few study on analyzing failure process and ultimate state of steel bearing when various loads assumed at the time of the earthquake apply. Therefore, the purpose of this study is to reveal the failure process and ultimate state of steel bearings under combined load by the finite element method (FEM). Fig.1 shows the damage situation of steel bearings. In this study pin bearing, pot bearing and pin-roller bearing discussed in detail according to the relationship between combined load and the corresponding displacement of each bearing, and its failure process.

(a) Example 1

(b) Example 2

Figure 1. Damage situation of steel bearing

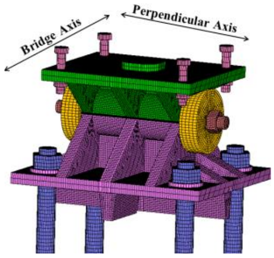
2. CONTENTS

2.1. Analysis method and modeling

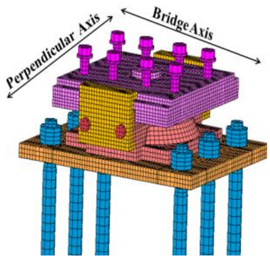
The numerical modeling develops for both longitudinal and transverse direction using multiple linear material properties and characteristics for each bearing. The design reaction force based on Japan Road Association Standard for all types of bearings is about 1500kN. In the analysis the model and outline fig.2 of the steel bearings were prepared by the FE software MSC.MENTAT/MARC, which used to simulate behavior of complex material and interaction under large deformation. All components of pin and pin-roller bearings are made of steel but pot bearing includes sandwiched rubber and brass ring in addition to steel. The analysis adapted von Mises yield criteria and isotropic Harding for all materials [2] and updated lagrangaian formulation for large deformation. The analysis set six analysis load cases shown in table 1. The applied boundary conditions for all bearings are similar; Fig.3 shows pin-roller bearing boundary condition. Penalty method was adapted method for the contact problems, many contact issues verified by comparing theoretical contact value with analysis result. As an example pin bearing cylindrical surface contact the equivalent stress distribution analysis result shown in fig.4, based on Japan Road Association Standard if the radius ratio of the bearing less than 1.02 then the theoretical value should be based on the road bridge specification and treated as a flat contact, so the bearing stress is determined by the following equation. [1]

$$\sigma = \frac{R}{A} \qquad (1)$$

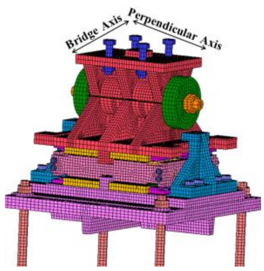
Where σ is bearing stress (N/mm^2), R is load (N) and A is projected area (mm^2) , by using Eq. (1) the theoretical result at the load of 1.2x 10^6 N become 49.23(N/mm^2) . The stress at the center of the cylindrical surface contact was 48.88 (N/mm2), and the analysis gave a value close to the theoretical value. Thus, the planar contact was also verified. [1]



(a) Pin bearing



(b) Pot bearing



(c) Pin-Roller bearing

Figure 2. FE Model and outline of bearing

Table 1: Analysis Load Case

Case	Load Condition
1	Dead load, displacement force in bridge axis
2	Dead load, displacement force in bridge perpendicular axis
3	Dead load, displacement force in 45° direction
4	Uplift load, displacement force in bridge axis
5	Uplift load , displacement force in bridge perpendicular axis
6	only Uplift load

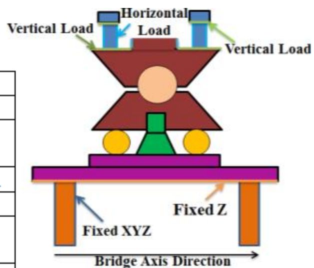


Figure 3. Pin-roller boundary condition.

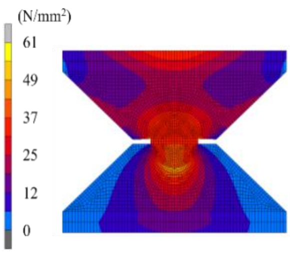


Figure 4. Equivalent stress distribution

Keywords: Bearing, combined loads, finite element method (FEM), analysis result, contact, fracture process.
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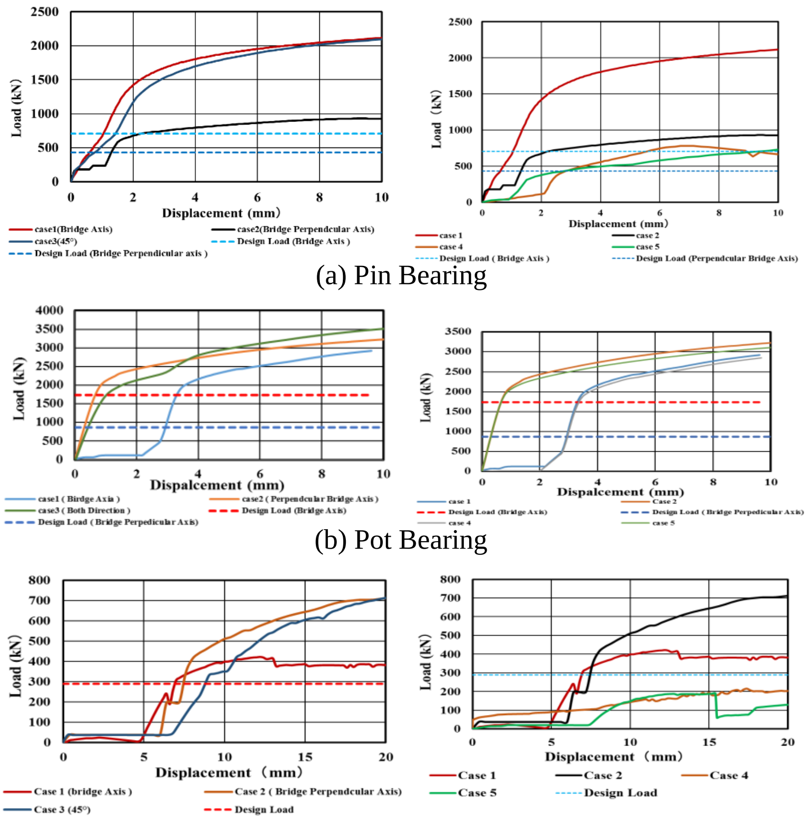
2.2. Analysis Result and Consideration
2.2.1. Load capacity of the bearings

Fig.5 shows the vertical and horizontal load-displacement comparison obtained from the analysis result. Case 1, 2 and 3 curves show that the analysis load capacity results are larger than the design load for all bearing types, this shows that the bearings initiated plasticity under expected design load, so the ultimate strength of the bearing had no longer fulfilled the design criteria to resist additional load increment. The load bearing capacity of the bearings also depends on the direction of horizontal load; there is large difference of load in pin and pin-roller bearing but for pot bearing the bridge axis direction had lower load capacity then another axis. [3]

In case 4 and 5, the load bearing capacity of pin bearing shows slightly decreased to the design load and pin-roller bearing shows less than the design load. In Pot bearing load capacity resistance for dead load and uplift load are almost similar. The analysis result also shows that the pin and pin-roller bearing had a capacity to a given uplift load but its initiated plasticity in a small amount of lifting load so the bearings are weak in lifting loads. [3]



(a) Pin Bearing

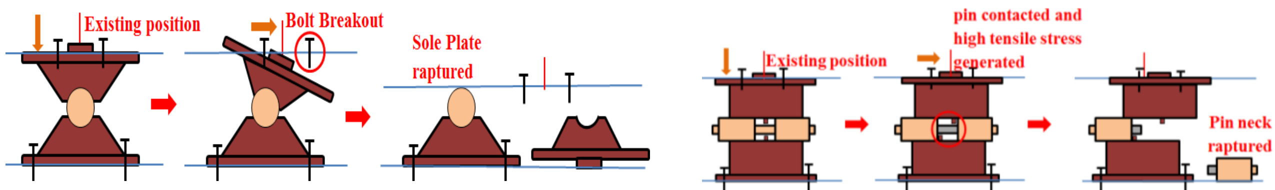
(b) Pot Bearing

(c) Pin-Roller Bearing

Figure 5. Load Displacement Curve

2.2.2. Failure process

Fig.6 shows the Failure process of pin bearing for bridge axis and bridge perpendicular axis according to the result obtained from the analysis. Pot bearing and pin-roller bearings are omitted due to the space. In case 1 high stress generated on the set bolt due to the rotation of the sole plate and pin, and it caused bolt break out of the set bolt. On the other hand case 2 generated high tensile stress on the neck of the pin due to the contact of sole and masonry plate with the steel pin in different time steps and loads, so the neck of the pin become raptured at the middle of the steel pin. The analysis results show that the fracture process and failure mechanism of the bearings are vary depends on the horizontal load direction.



(a) Case 1 (Bridge Axis)

(b) Case 2 (Bridge Perpendicular Axis)

Figure 6. Failure process of pin bearing

3. CONCLUSION

The study revealed that the analysis result of pin and pin-roller bearing show that lower lifting load than the design load, this means that the load capacity of the bearings had a capacity to resist the loaded uplift load but the fracture mechanism and load bearing capacity depends on the horizontal load direction. For pot bearing the effect of vertical loads are almost similar and horizontal loads affected fracture process of the bearing depends on the direction of the applied loads. Based on the analysis result the horizontal loading direction has a large influence on the load carrying capacity and the failure process.

4. REFENCE

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2. Japan Road Association: Road Bridge Specifications / Commentary I Common Edition, 2002.3.
3. Javier Bonet and Richard D.Wood. Nonlinear Continuum Mechanics for Finite Element analysis. New York, NY: Cambridge University Press, 2008, pp 188-215.