# 論文 Effects of Change of Boundary Conditions from Rigid to Elastic Supports on Slab Behavior

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ABSTRACT: When converting simply supported single span bridge structures to continuous structures, elastic support conditions in the horizontal direction are provided to absorb the energy of earthquake loading and to distribute the horizontal reaction due to temperature change. However, a possibility of additional stress increase in the transverse cross section of the slab due to the vertical elastic bearings seems to be overlooked in the design process. A verification test with simple beam bridge specimen indicates a significant increase of strain in the transverse direction under the elastic support conditions and a counter-measurement for this increase needs to be provided in the design.
KEY WORDS: elastic supports, stress in the transverse direction

## 1. INTRODUCTION

As the design load is increased from T-20 to T-25, existing bridge structures have to be examined for their safety against the increased design load. Converting the existing simple beam bridges to a continuous bridge has been thought as a practical method for strengthening. When converting the structural type to the continuous spans, changes in both vertical and horizontal reactions are the most difficult problem to deal with. Recently, with the development of elastic bearing materials, those changes are frequently adopted with the change of metal bearings into elastic supports[1]. To strengthen the existing simple span structures, Hansin Expressway Public Corporation suggests several designs of the conversion. Detailed specifications are provided in the Highway Bridge Design Manual for Aseismic Design(draft)[2]. When adjacent girders and/or concrete slabs are connected with each other, support conditions have to be changed as illustrated in Fig. 1. When the vertical spring constant are infinitely large like metal bearings, section x-x(Fig.1) would be subjected to a large moment because of a short span

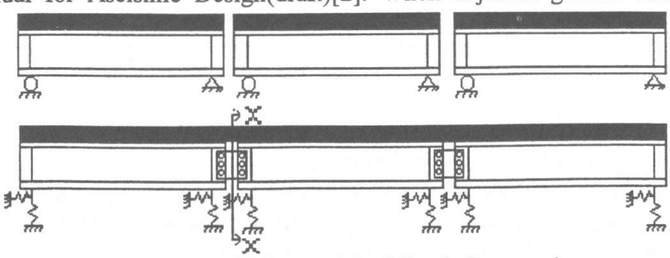


Fig. 1 Structural Conversion of Simply Supported Spans to a Continuous Structure

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length. Piers would also be exposed to a increased vertical reactions under the live load. The vertical spring constant for the elastic supports is chosen so that the change of the reactions would not be large enough to cause over- stress of the bridge piers[3]. The horizontal springs are provided so that the horizontal reactions under both earthquake load and temperature change can be dispersed to all the piers.

Very often, especially after the disasters of the Great Hansin Earthquake, use of the elastic support condition to absorb the energy of earthquake loading has been speeded up. While doing such work, the effect of the vertical sinking of the supports on the slab due to the live (traffic) load has not been given much thought based on the fact that the conversion would only reduce the stress of the slab in the longitudinal direction. In contrary, due to the differential settlement of the bridge supports, when the elastic boundary is used, an additional moment to the slab in the transverse direction is presumed. A simply supported steel- concrete composite bridge specimen is set up to test the slab behavior due to the changes of the boundary conditions. As a preliminary step to test the effect of the elastic supports, the tests are conducted by varying the boundary conditions from rigid to elastic supports and the results are reported in this paper.

## 2. SET-UP OF THE TEST SPECIMEN

The tests are conducted on a simply supported composite specimen composed of precast concrete slabs on two steel girders. The test specimen is shown below in Fig. 2.

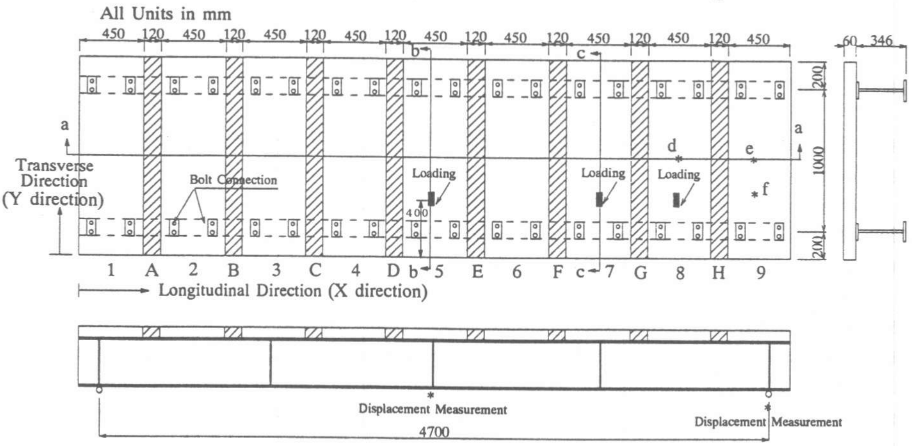



Fig. 2 The Test Specimen

The specimen size is about 1/6 of an actual simply supported single span bridge and the assembly is performed in the following orders;

(1) placement of precast slabs (numbered 1 to 9) on the support girders
(2) casting of concrete in the joint(designated from A to H)between two adjacent pre cast slabs, and
(3) placement of elastic bearing under the girders.

The longitudinal rebars for each pre cast slab are connected at each joint by lap-joint method and expansive concrete is casted. The properties of concrete materials are given in Table 1. Strains in the longitudinal direction (x direction ) are measured on the top and bottom surfaces of the section a-a (Fig. 2). Strains in the transverse direction (y direction) are

Table 1 Material Properties of Concretes

| Types | Compressive Strength | Young's Modulus | Poisson's Ratio |
|---|---|---|---|
| Precast slabs | 288 ($kgf/cm^2$) | $3.42 \times 10^5$ ($kgf/cm^2$) | 0.191 |
| Joints | 321 ($kgf/cm^2$) | $2.72 \times 10^5$ ($kgf/cm^2$) | 0.184 |

measured along the sections b- b and c- c (bottom surface only). Measurement of strains along three different directions(rosette gages are used) at the points d, e, f (bottom surface only) are taken and the displacements at the elastic supports and mid-span of the girders are also measured.

Loadings are conducted at three different locations, panels 5, 7 and 8 for every selected bearing conditions. The results for loading on the panels 5 and 7 are used to compare the strain distributions along the sections a- a, b- b and c- c with respect to different supports conditions. Loading on the panel 8 is used to compare the changes of the maximum shear strains and principal strains at the points d, e, f (Fig. 2) near the support. Testing is done with 3 different support conditions. First , the test is carried out on the rigid supports(spring constant = infinity). Following tests are conducted under two different elastic support conditions. Loading positions are at y = 40 cm on all three panels.

## 3. SELECTION OF ELASTIC BEARING MATERIAL

As a first step, a linear elastic material is chosen for the test. Preliminary, a pipe section is decided to be used as an elastic bearing material because a round section is expected to behave linearly if displacement is small. Several pipe sections are analysed for their suitability using FEM of plane stress elements. The bearing material which satisfied two given conditions is selected;

(1) the maximum stress under the dead and live load is below the yield point, and

(2) the spring constant is about 1/6 of the actual bearing material used in practice. About 400,000Kgf/cm is the actual value used in practice [3].

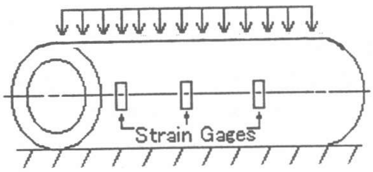


Fig. 3 Test for Elastic Properties of the Pipe

Based on the analysis results, the pipe section with outside diameter of 42.7 mm and thickness of 3.5 mm is chosen. The chosen section is also subjected to the test to determine its displacement- force relationship. The material test set- up is as given in Fig. 3. Test and analysis results are given in Table 2. Spring constants obtained from the experiment are also used as analysis input data.

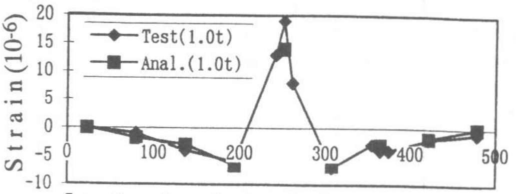
Table 2 Property of Elastic Bearing Material

| Property | 17 cm pipe (kgf/cm) | | 12 cm pipe (kgf/cm) | |
|---|---|---|---|---|
| Spring Constant | Analysis | Test | Analysis | Test |
| | 58,412 | 56,661 | 41,231 | 39,996 |

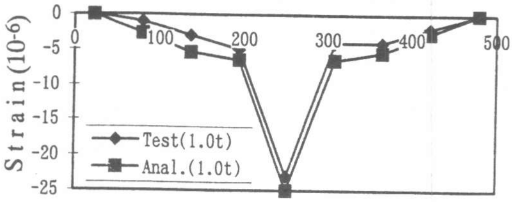
## 4. THE TEST RESULTS

### 4.1 STRAIN DISTRIBUTION ALONG THE LONGITUDINAL DIRECTION

First of all, a linear analysis for the test specimen is performed under the design load of 1.0 (ton) to verify the reliability of the test results. Shown in Fig. 4 is the comparison of the strain distributions obtained from the test and analysis. Figs 4 (a) and (b) indicate strain distributions in the top and bottom surfaces along the section a- a (Fig. 2) when load is located on the panel 5 under the rigid boundary condition. Tendency between two results are in a good agreement This validates the legitimacy of the test results. Figs. 5 and 6 indicate strain distributions in the longitudinal direction with respect to different boundary conditions of rigid and elastic ones. The loading location is on the panel 5 for Fig. 5 and the panel 7 for Fig. 6. The strain values at some distance away from the load indicate compression on both top and bottom surface. This is because whole structure acts as a composite beam. That is, the neutral axis of the composite section is located in the main girder below the slab. However, the bottom surface near the load is exposed to tensile strain due to the



Location along the Longitudinal Direction (cm)
(a) Strain Distribution on the Bottom Surface



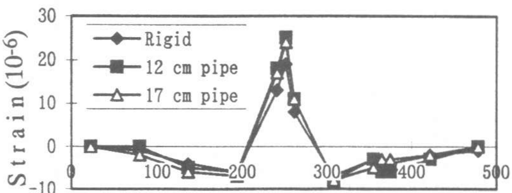
Location along the Longitudinal Direction (cm)
(b) Strain Distribution on the Top Surface

Fig. 4 Comparison of Test and Analysis Results

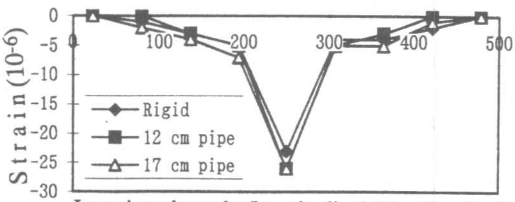
local slab sagging. Both Figs. 5 and 6 show only small variations of strain along the longitudinal direction when the boundary conditions are changed. If simply supported single spans are connected to become a continuous structure, these strain values are expected to drop(in their absolute values) at the middle of the span and rise towards the end of the span. The observation of the longitudinal strain distribution points out that the usage of elastic boundary may be practised as it has been without causing any additional stress in the longitudinal direction.

## 4.2 STRAIN DISTRIBUTION ALONG THE TRANSVERSE DIRECTION

Strain distributions along the transverse direction in the sections b- b and c- c with respect to a various load under the rigid boundary condition are shown in Fig. 7. Fig. 8 is the transverse strain distribution in the sections b- b and c- c under a various support conditions. Load is 1.0 ton for Fig. 8. Loading positions for Figs. 7(a) and 8(a) are the panel 5. The panel 7 is loaded for Figs. 7(b) and 8(b). If a linear load- strain relationship is assumed from Figs 7(a) and (b), the increment of strain

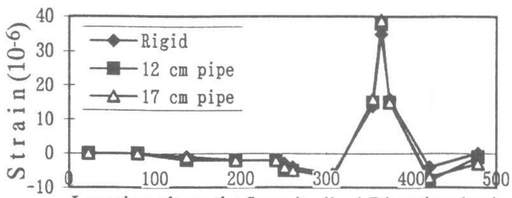


Location along the Longitudinal Direction (cm)
(a) Strain Distribution on the Bottom Surface

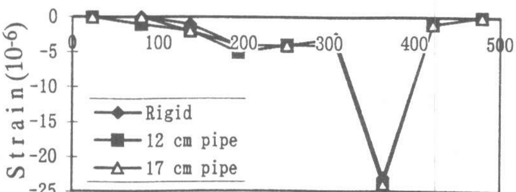


Location along the Longitudinal Direction (cm)
(b) Strain Distribution on the Top Surface

Fig. 5 Longitudinal Strain Distribution by Changing the Boundary Condition (Loading on Panel 5)



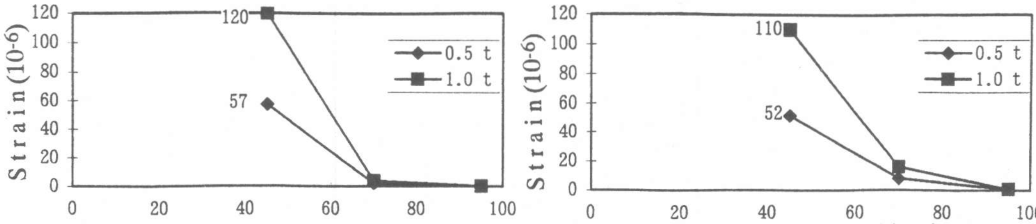
Location along the Longitudinal Direction (cm)
(a) Strain Distribution on the Bottom Surface



Location along the Longitudinal Direction (cm)
(b) Strain Distribution on the Top Surface

Fig. 6 Longitudinal Strain Distribution by Changing the Boundary Condition (Loading on Panel 7)

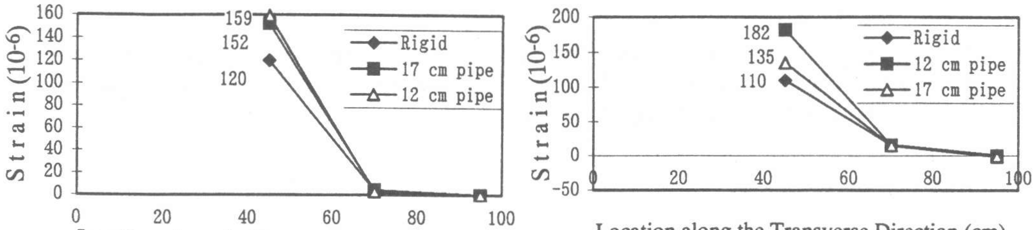
values in the transverse direction (Fig.8) due to the change of boundary condition from rigid to 17 cm pipe is approximately equivalent to 0.25 ton of load increase under the rigid boundary condition. Strain increase from $120 \times 10^{-6}$ to $152 \times 10^{-6}$ (refer to Fig. 8(a)) represents the moment growth from 325 kgf·m/m to 415 kgf·m/m as rigid bearing is changed to 17 cm pipe bearing. This increase of moment is due to a larger differential displacement between two main girders when elastic bearing is in place (refer to Fig. 9). The measured differential settlement of two main girders at the mid-span is given in Table 3 while the differential settlement at the supports is shown in Table 4. Both




(a) Strain Distribution of the section b-b

(b) Strain Distribution of the section c-c

Fig. 7 Transverse Strain Distribution by Changing the Load




(a) Strain Distribution of the section b-b

(b) Strain Distribution of the section c-c

Fig. 8 Transverse Strain Distribution by Changing the Boundary Condition

Fig. 8(a) and Table 3 indicate a rapid increase of their respective values as the boundary conditions are changed form rigid to 17cm pipe. Only a small change is recorded as the boundary is changed from 17 cm to 12 cm pipe. Contrarily, Fig. 8(b) and Table 4 show a continued growth in their values. From the results, it may be concluded that the effect on the slab due to the change of boundary condition is greater near the supports as the elastic supports become softer. These strain increase seems not to be a negligible amount. Additionally, a large impact load is assumed on the slab between two closely located inner supports (section x- x in Fig.1) because of a short span length. This additional factor is anticipated to add even greater stress increase.

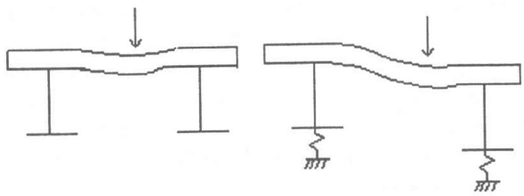


Fig. 9 Increase of Differential Displacement due to the Elastic Boundary Condition

Table 3 Differential Settlement of Two Girders at the Mid-Span When Loaded on the Panel 5

| Loading Locations | Rigid | 17 cm pipe 56,661kgf/cm | 12 cm pipe 39,996kgf/cm |
|---|---|---|---|
| Panel 5 | 0.026 cm | 0.037 cm | 0.039 cm |

Table 4 Differential Settlement of Elastic Bearing Supports When Loaded on the Panel 8

| Loading Locations | Rigid | 17 cm pipe 56,661kgf/cm | 12 cm pipe 39,996kgf/cm |
|---|---|---|---|
| Panel 7 | 0.000 cm | 0.008 cm | 0.013 cm |

## 4.4 INCREASE OF PRINCIPAL AND MAXIMUM SHEAR STRAIN

At any location where strains are measured with rosette gages, the principal and maximum shear strains could be obtained. Rosette gages are used to measured the strains at the points d, e, and f near the support. Table 5 illustrates the changes of the principal and maximum shear strains as the boundary conditions are changed. Loading location is on the panel 8. As the softer elastic material is used, increase of the principal and maximum shear strains is clear. Again, the most apparent increase is at the point f , the nearest from the support. As the results indicate, it is very important to check the effect on the slab when the conversion of simply supported single spans to a continuos span is planned. Especially, the stress increase near the supports has to be carefully examined and accounted for in the design.

Table. 5 Principal and Maximum Shear Strain

| B. C. / Locations | Rigid | 17 cm pipe 56,661kgf/cm | 12 cm pipe 39,996kgf/cm |
|---|---|---|---|
| Principal Strains and Max. Shear Strain Point 'd' (Panel 8) | Prin.Str.= 20.4<br>17.8<br>Max.Sh.= 4.2 | Prin.Str.= 26.8<br>11.2<br>Max.Sh.= 7.8 | Prin.Str.= 29.3<br>10.7<br>Max.Sh.= 9.3 |
| Principal Strains and Max. Shear Strain Point 'e' (Panel 9) | Prin.Str.= 19.0<br>-4.0<br>Max.Sh.= 11.5 | Prin.Str.= 21.8<br>-6.8<br>Max.Sh.= 14.3 | Prin.Str.= 25.3<br>-3.3<br>Max.Sh.= 14.3 |
| Principal Strains and Max. Shear Strain Point 'f' (Panel 9) | Prin.Str.= 20.4<br>-4.4<br>Max.Sh.= 12.4 | Prin.Str.= 32.2<br>-5.2<br>Max.Sh.= 18.7 | Prin.Str.= 38.2<br>-6.2<br>Max.Sh.= 22.2 |

## 5. CONCLUSION

A simple span bridge specimen is tested to study the behavior of the slab due to the change of rigid conditions to elastic conditions. The test results indicate a much increase of strain in the transverse direction and shear stress when rigid boundary conditions are changed to that of the elastic ones. It also indicates that the increase of strain near the supports is greater in its magnitude as the elasticity becomes softer. The increase is caused by even a little differential settlement of the main girders when elastic supports are used. Slab, cross beams, or sway bracings nears the supports may be subjected to an additional stress due to the placement of elastic boundary. The usage of elastic supports to prevent damages from earthquake that may not even occur during the duration of the service period exposes the slab to a higher stress level. This may cause a faster fatigue deterioration due to everyday traffic loads[4]. Therefore, a careful verification should be carried out before the field works.

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