# SEIMIC DESIGN OF A LONG-SPAN CONTINUOUS STEEL TRUSS BRIDGE

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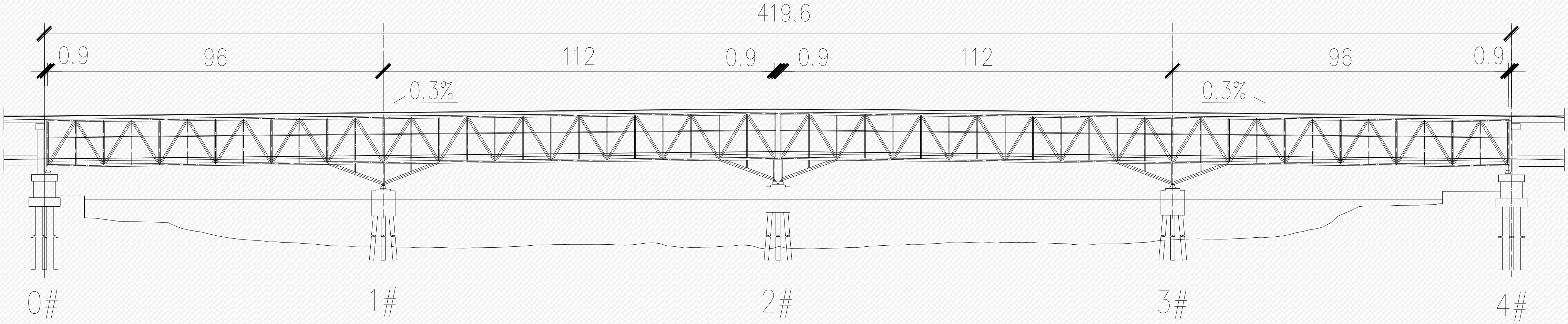
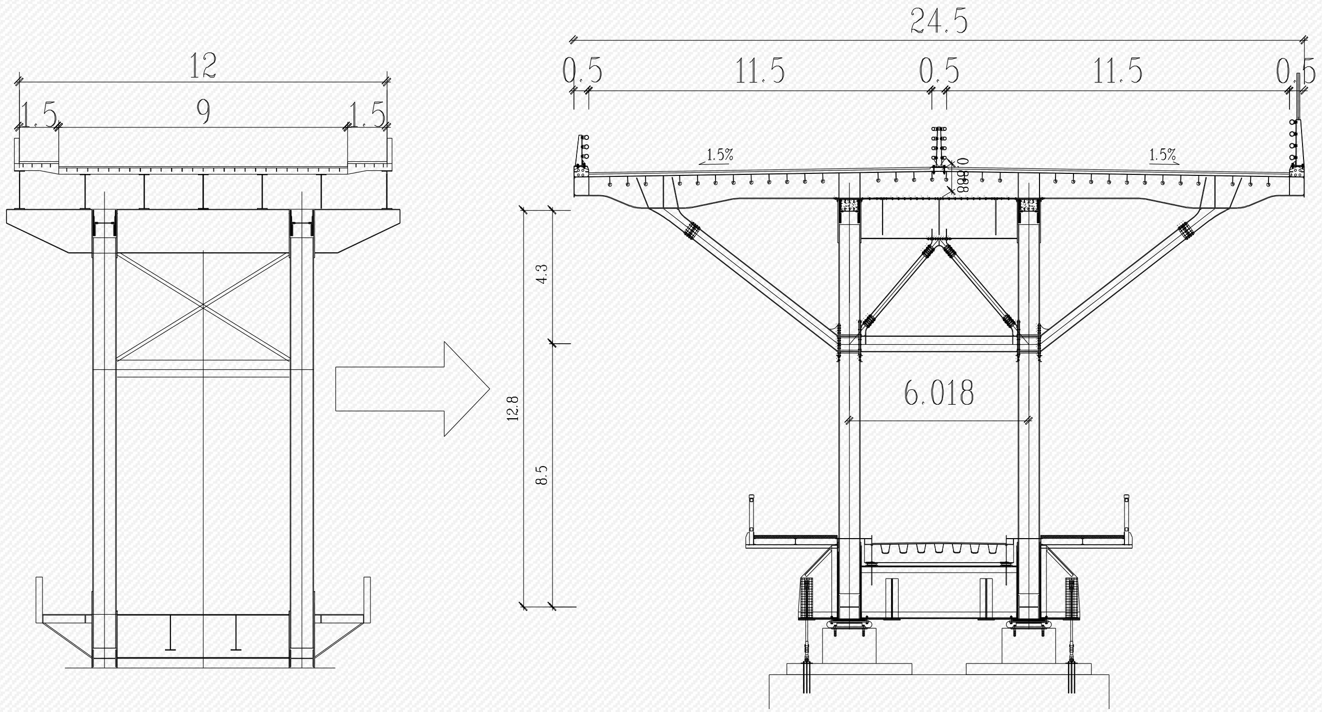
# 1、Project Overview

➢The old Songpu Bridge was a railway and highway combined bridge across the Huangpu River. The upper deck was a two-lane highway and the lower deck was a single-track railway. In recent years, the Songpu Bridge needs reconstruction to make full use of the existing resources.

➢The main bridge is a continuous steel truss bridge with the span arrangement (96m+112m+112m+96m). Middle piers (1#~3#) are supported on the concrete-filled steel tubular pile foundations, while end piers (0# and 4#) are on the drilling cast-in-place pile foundations.



The upper deck of the main bridge adopts steel-concrete composite bridge deck with plate and truss combined structure system, and is widened from the original two lanes to two-way six lanes, with the support of the diagonal struts to improve the stress condition of the bridge after widening. Meantime, the lower deck using the orthotropic steel deck system is supported on the rubber bearings placed on the main truss for non-automobile lanes and sidewalks.




So the self-weight of the bridge superstructure is obviously increased after widening and reconstruction, yet it is difficult to reinforce the old pile foundations due to the strict construction conditions, which may adversely affect the seismic performance of the bridge. Meantime, the bridge after widening and reconstruction has to meet the current Chinese bridge seismic specifications , which asks for a due seismic study of the reconstructed bridge.

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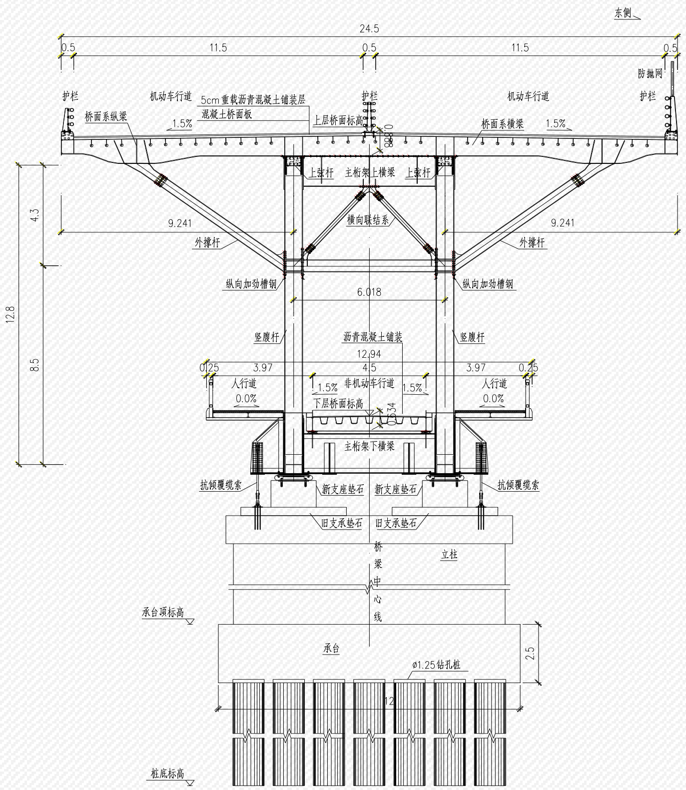
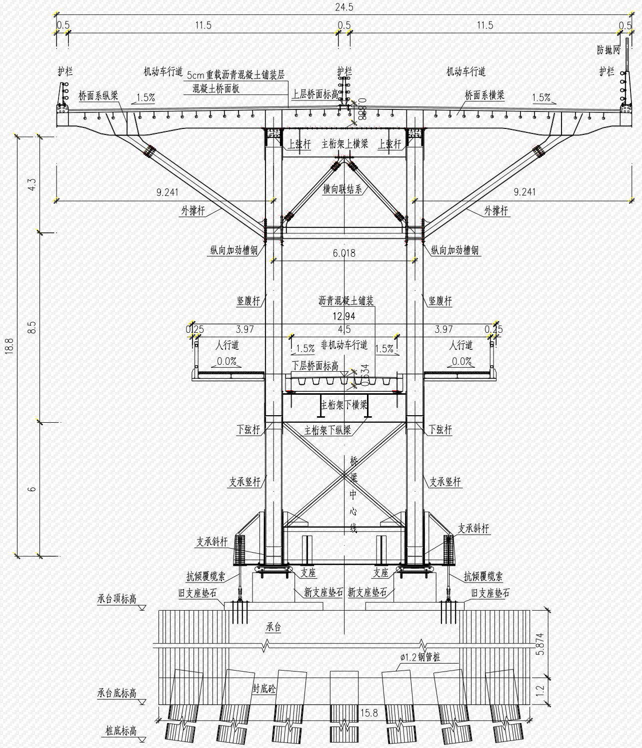
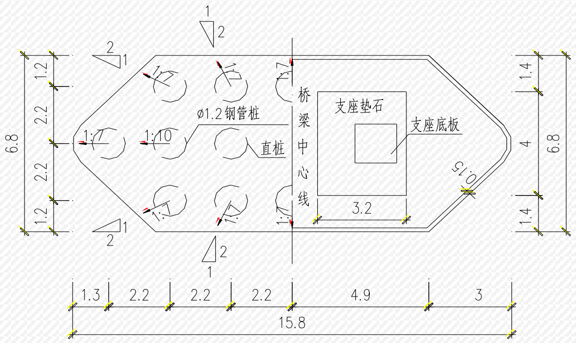
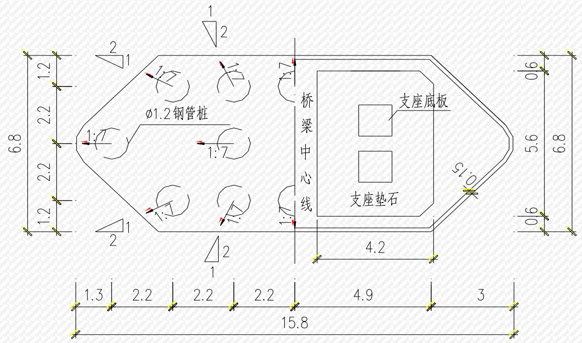


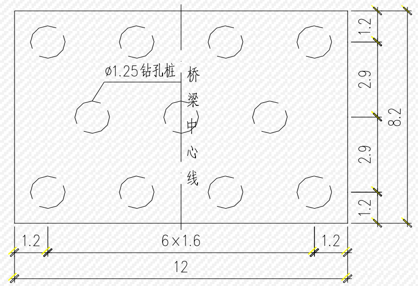

1#、3#墩1/2承台底桩位及顶帽平面图 1:200



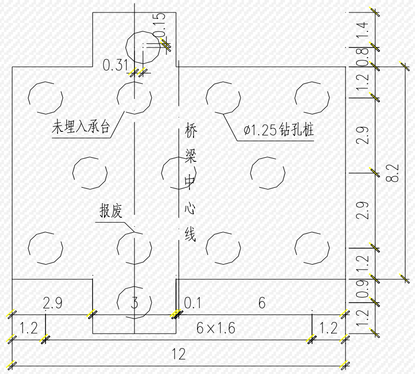

2#墩1/2承台底桩位及顶帽平面图 1:200




0#台1/2承台底桩位平面图 1:200



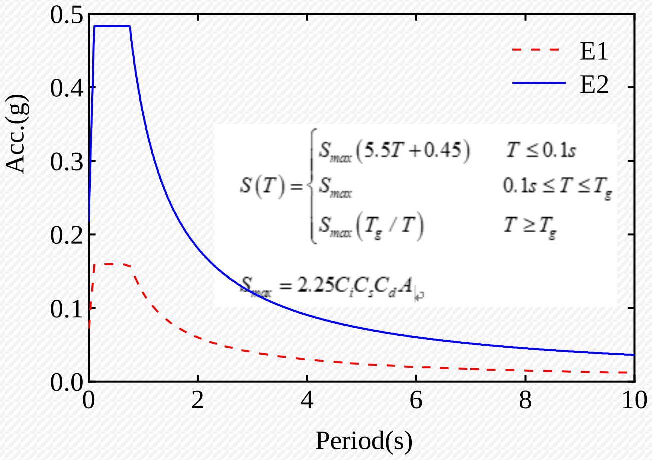

4#台1/2承台底桩位平面图 1:200

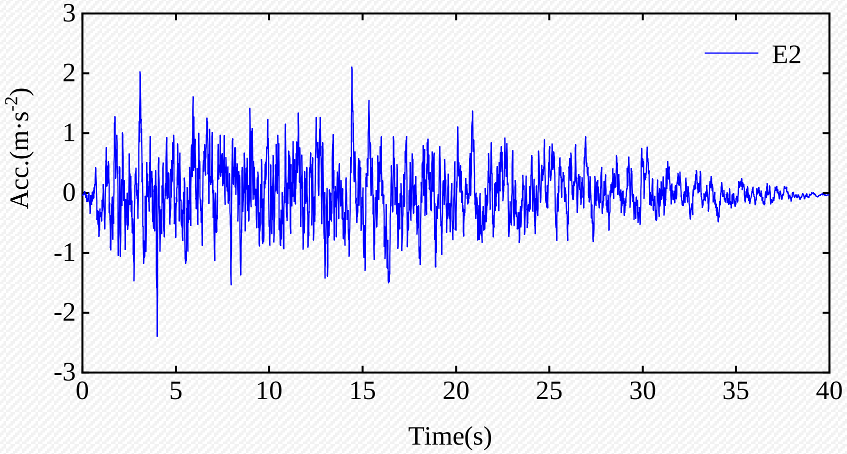


## 2、Seismic fortification criteria

- Two fortification levels, including E1 and E2, are adopted according to the Chinese specifications.
- The ground motion inputs include the longitudinal direction coupled with the vertical direction (L+V) and the transverse direction coupled with the vertical direction (T+V).

| Fortification level | Return period | Performance objectives | Seismic requirements |
|---|---|---|---|
| E1 | 75 | Elastic | The main truss remains elastic, and the bending moment of the pile foundation is less than the initial yield moment. |
| E2 | 1000 | The main truss remains elastic, and the pile foundations can continue to be used without repair or with minimal repair. | The main truss remains elastic, and the bending moment of the pile foundation is less than the equivalent yield moment. |

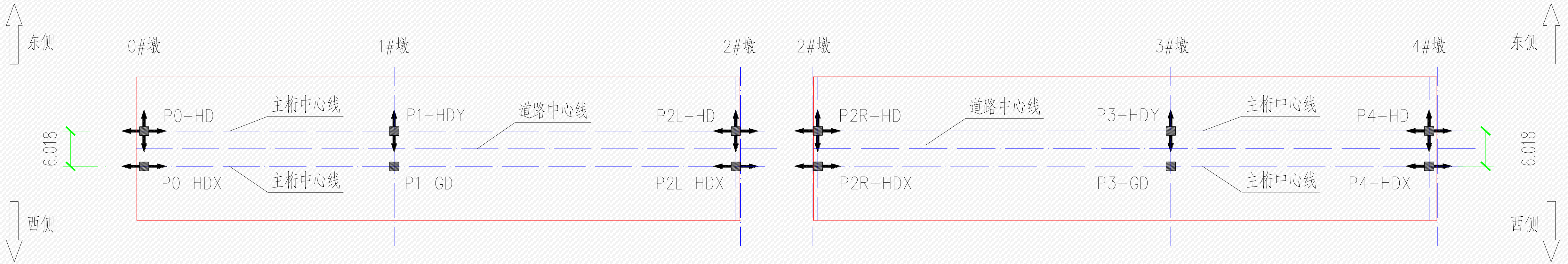



The continuous steel truss bridge is located on IV soil type site, which represents a comparatively soft soil foundation. The seismic fortification intensity is 7 degrees and the characteristic period $T_g$ is 0.75s.

## 3、Analysis model

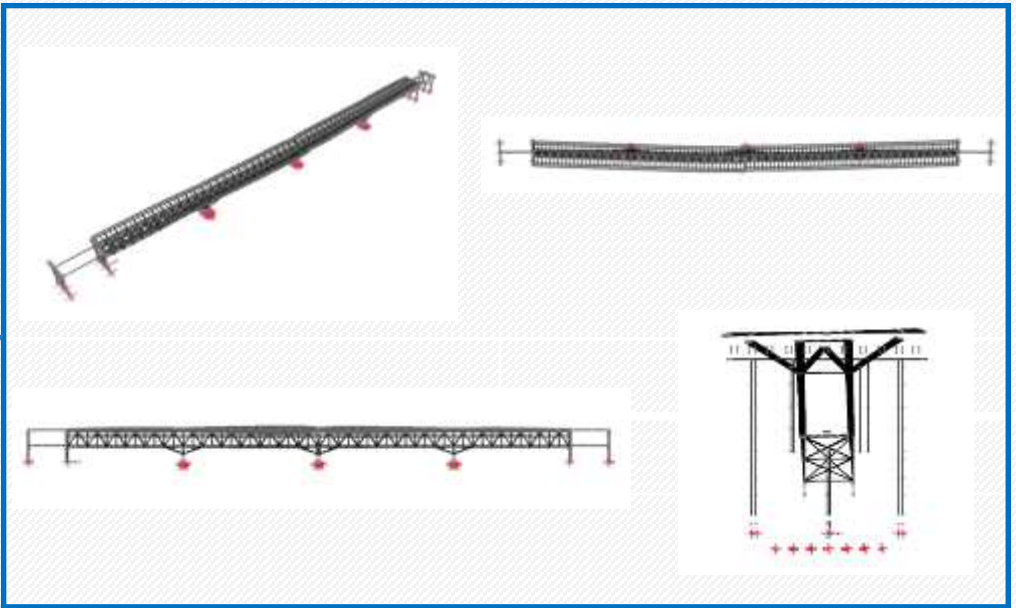
- Piers and truss are simulated by elastic beam elements. The pile cap is regarded as a rigid body with the mass concentrated on the centroid, and the secondary dead load is applied uniformly to the bridge deck system.
- The spherical bearings (P0~P4) are adopted, with the arrangement shown in the following picture.

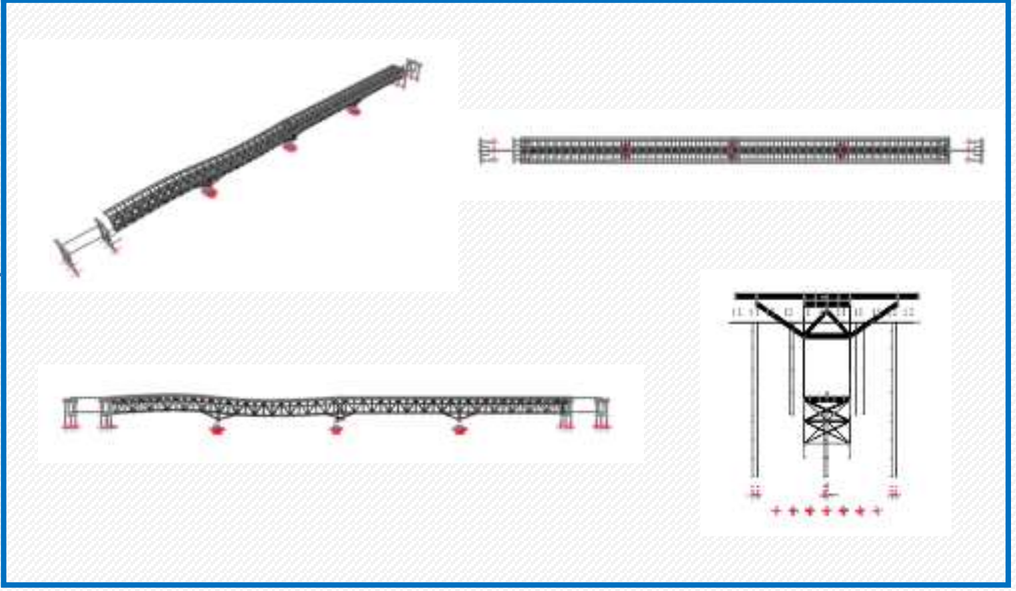


# 4、Dynamic characteristics

The top six vibration models are shown in the following table.

| Order | Period/s | Frequency/Hz | Vibration characteristics |
|---|---|---|---|
| 1 | 1.530 | 0.654 | Symmetrical transverse bending |
| 2 | 1.475 | 0.678 | Unsymmetry transverse bending |
| 3 | 1.194 | 0.838 | Symmetrical transverse bending-torsional coupling |
| 4 | 1.166 | 0.858 | Unsymmetry transverse bending-torsional coupling |
| 5 | 1.134 | 0.882 | Longitudinal drift of the left bridge span |
| 6 | 1.050 | 0.952 | Longitudinal drift of the right bridge span |





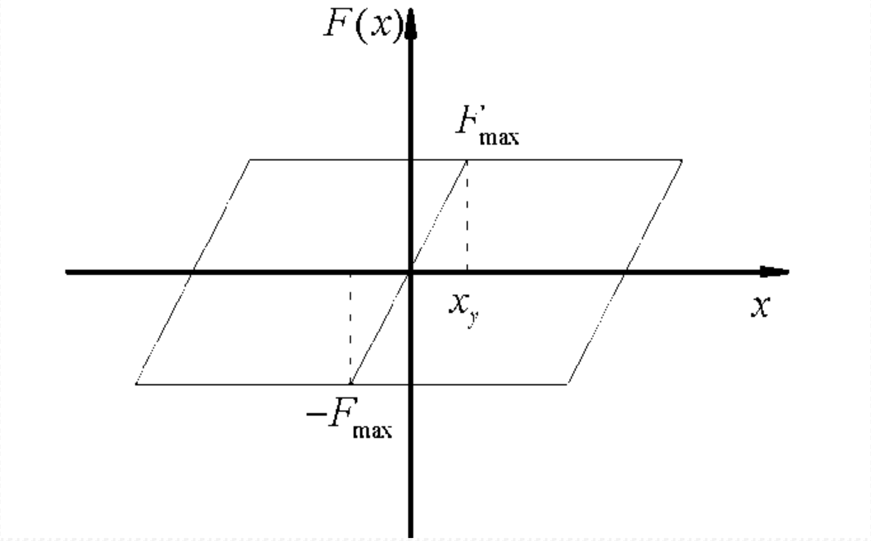
## 5、Seismic conceptual design

- First, the seismic performance has to be checked to determine whether it meets the seismic requirements. The following conditions are considered:

  1）The spherical bearings are not sheared off under earthquake.

  2）The spherical bearings are sheared off under earthquake.

- The bilinear elastoplastic spring (Plastic-Wen) element is adopted to simulate the sliding friction effects of the spherical bearings shown in the following picture. ($\mu$=0.02, $F_{max}=\mu\times$W(vertical reaction force of the bearing under dead load), $X_y$=3mm)



## 1) spherical bearings are not sheared off

Nonlinear time-history analysis is conducted to obtain the seismic response, and key targets are checked based on the strength-demand ratio (SDR).

- E1:

(1) L+V:

| Pile | Axial load | mon | | Initial yield moment | SDR |
|---|---|---|---|---|---|
| 1# | 64 | 26. | | 4311 | 2.03 |
| 2# | 1567 | 17 | | 4071 | 1.93 |
| 3# | 659 | 18 | | 4330 | 2.66 |

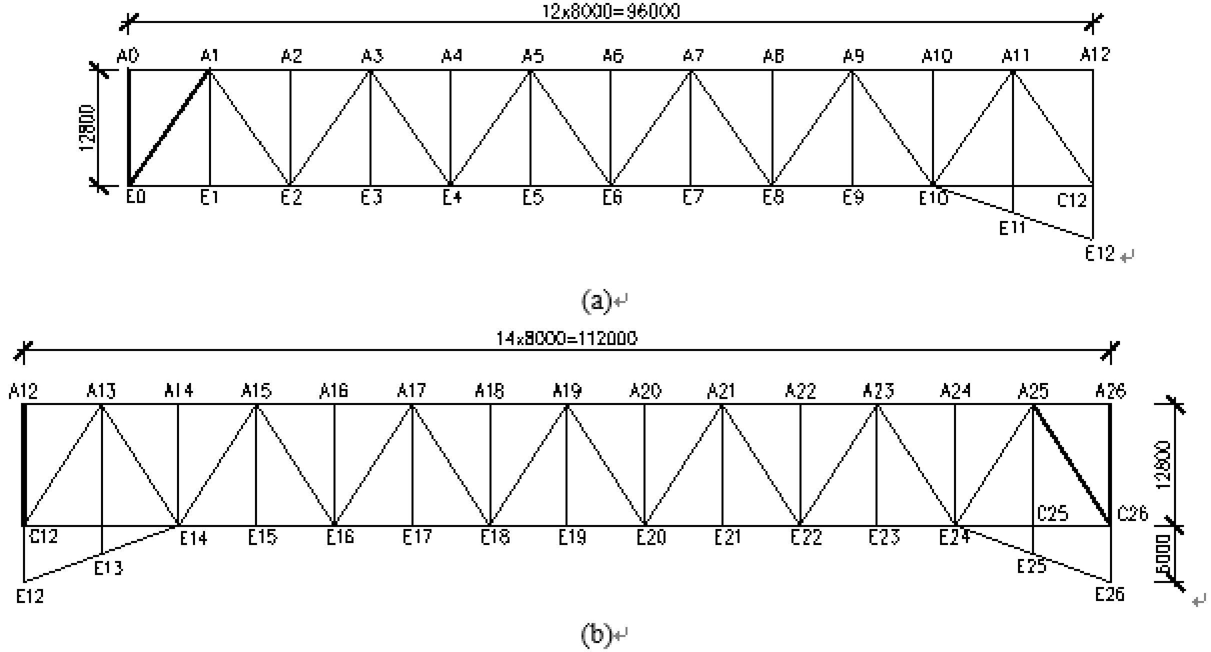


Fig.4. Checking targets of the main truss; (a) The left span of a bridge, (b) The right span of a bridge.

| Truss | Stress | Yield | |
|---|---|---|---|
| E0A0 | 33 | 27 | |
| E0A1 | 80 | 27 | |
| A12C12 | 57 | 270 | 4.74 |
| A25C26 | 111 | 270 | 2.43 |
| A26C26 | 48 | 270 | 5.63 |

| | | s | SDR |
|---|---|---|---|
| | | | 1.64 |
| | | | 2.25 |
| A12C12 | 145 | 270 | 1.86 |
| A25C26 | 171 | 270 | 1.58 |
| A26C26 | 250 | 270 | 1.08 |

## 1) spherical bearings are not shear off

➢ E2：

（1）L+V：

| Pile | Axial load | moment | Initial yield moment | SDR |
|---|---|---|---|---|
| 1# | -6621 | 7493 | 4677 | 0.62 |
| 2# | -900 | 4917 | 6369 | 1.30 |
| 3# | -5228 | 5428 | 5073 | 0.93 |

| Truss | Stress | Yield stress | SDR |
|---|---|---|---|
| E0A0 | 43 | 270 | 6.28 |
| E0A1 | 113 | 270 | 2.39 |
| A12C12 | 75 | 270 | 3.60 |
| A25C26 | 140 | 270 | 1.93 |
| A26C26 | 60 | 270 | 4.50 |

➢ L+V： The seismic bending moments of 1# and 3# pile foundations are not enough.

（2）T+V：

| Pile | Axial load | moment | Initial yield moment | SDR |
|---|---|---|---|---|
| 1# | -1905 | 5268 | 6066 | 1.15 |
| 2# | -3912 | 5505 | 5464 | 0.99 |
| 3# | -1949 | 4130 | 6053 | 1.47 |

| Truss | Stress | Yield stress | SDR |
|---|---|---|---|
| E0A0 | 439 | 270 | 0.62 |
| E0A1 | 235 | 270 | 1.15 |
| A12C12 | 294 | 270 | 0.92 |
| A25C26 | 287 | 270 | 0.94 |
| A26C26 | 572 | 270 | 0.47 |

➢ T+V： The seismic bending moments of 2# pile foundation and some key rods strength are not enough.

## 2) Sheared-off spherical bearings

So it is necessary to consider that spherical bearings will be sheared off under E2 earthquake. Then the seismic response is obtained to check the key targets.

- E2:

(1) L+V:

| Pile | Axial load | moment | Initial yield moment | SDR |
|---|---|---|---|---|
| 1# | 1421 | 2780 | 7028 | 2.53 |
| 2# | 38 | 3575 | 6640 | 1.86 |
| 3# | 1059 | 2460 | 6929 | 2.82 |

| Truss | Stress | Yield stress | SDR |
|---|---|---|---|
| E0A0 | 63 | 270 | 6.28 |
| E0A1 | 103 | 270 | 2.39 |
| A12C12 | 63 | 270 | 3.60 |
| A25C26 | 127 | 270 | 1.93 |
| A26C26 | 57 | 270 | 4.50 |

- The maximum bearing deformation is around 239mm.

(2) T+V:

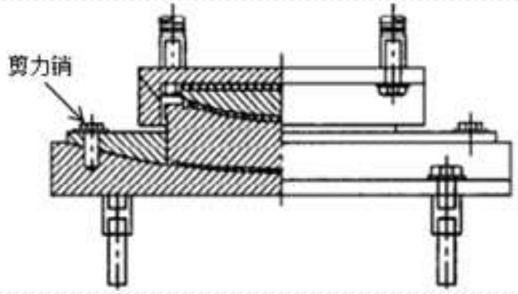
| Pile | Axial load | moment | Initial yield moment | SDR |
|---|---|---|---|---|
| 1# | 2228 | 4895 | 7251 | 1.48 |
| 2# | 1572 | 5153 | 7071 | 1.37 |
| 3# | 1831 | 4008 | 7142 | 1.78 |

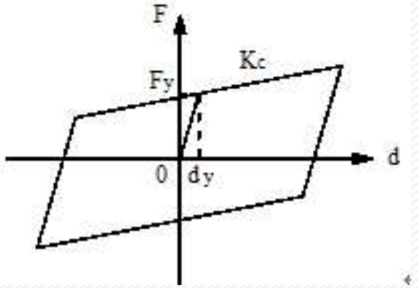
| Truss | Stress | Yield stress | SDR |
|---|---|---|---|
| E0A0 | 119 | 270 | 2.27 |
| E0A1 | 124 | 270 | 2.18 |
| A12C12 | 105 | 270 | 2.57 |
| A25C26 | 148 | 270 | 1.82 |
| A26C26 | 135 | 270 | 2.00 |

- The maximum bearing deformation is around 214mm.

## 3) Summary

- When the spherical bearings are not allowed to sheared off, the key checking targets all meet the seismic requirements under E1 earthquake. But the seismic demands of the pile foundations and some key rods of the main truss are not satisfied under E2 earthquake.
- When the spherical bearings are allowed to sheared off under E2 earthquake, the key checking targets can all meet the seismic requirements. However, the bearing deformations are comparatively large, and the maximum deformation exceeds 200mm.
- Considering lack of displacement restrainer and also ductile components, the seismic isolation design is prefer to a ductile seismic design for this reconstructed bridge.




# 6、Seismic isolation design

## FIRST SCHEME：Friction pendulum bearing

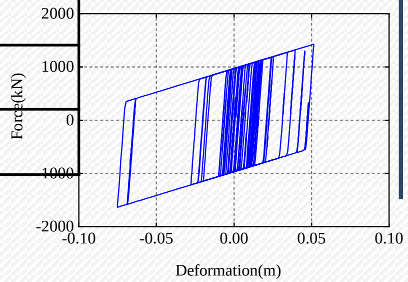
All spherical bearings are replaced by friction pendulum bearings with the isolation period *T*=3s. And key checking targets can meet the seismic requirements under E2 earthquake.

- E2：

（1）L+V：

| Pile | Axial load | moment | Initial yield moment | SDR |
|---|---|---|---|---|
| 1# | -878 | 4618 | 6376 | 1.38 |
| 2# | -446 | 3723 | 6502 | 1.75 |
| 3# | -273 | 3138 | 6551 | 2.09 |

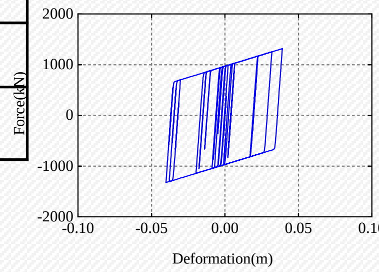
| Truss | Stress | Yield stress | SDR |
|---|---|---|---|
| E0A0 | 43 | 270 | 6.28 |
| E0A1 | 101 | 270 | 2.67 |
| A12C12 | 64 | 270 | 4.22 |
| A25C26 | 126 | 270 | 2.14 |
| A26C26 | 56 | 270 | 4.82 |



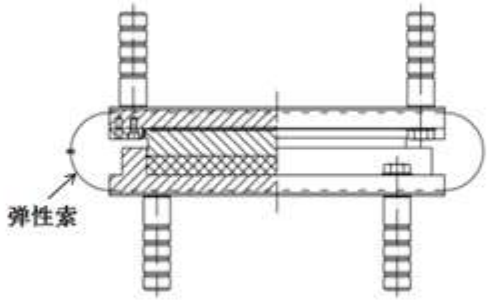

（2）T+V：

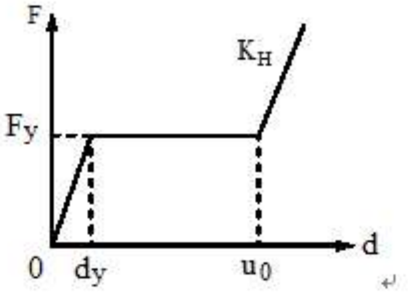
| Pile | Axial load | moment | Initial yield moment | SDR |
|---|---|---|---|---|
| 1# | 1315 | 4762 | 6998 | 1.47 |
| 2# | 797 | 5094 | 6857 | 1.35 |
| 3# | 1339 | 3694 | 7006 | 1.90 |

| Truss | Stress | Yield stress | SDR |
|---|---|---|---|
| E0A0 | 173 | 270 | 1.56 |
| E0A1 | 142 | 270 | 1.90 |
| A12C12 | 169 | 270 | 1.60 |
| A25C26 | 180 | 270 | 1.50 |
| A26C26 | 226 | 270 | 1.19 |



# 6、Seismic isolation design




## SECOND SCHEME：Cable-sliding aseismic bearing

Design parameters of the cable-sliding aseismic bearing, such as the free length (0.12m) and the horizontal stiffness of the cable ($15\times10^4$kN/m), are identified by parametric analysis. Because the 0#, 2# and 4# pile foundations have comparatively large strength margin, bearings on these foundations are all replaced by cable-sliding aseismic bearings. Then key checking targets can meet the seismic requirements under E2 earthquake.

- E2：

（1）L+V：

| Pile | Axial load | moment | Initial yield moment | SDR |
|---|---|---|---|---|
| 1# | 1094 | 3158 | 6938 | 2.20 |
| 2# | -645 | 4382 | 6445 | 1.47 |
| 3# | 1014 | 2741 | 6917 | 2.52 |

| Truss | Stress | Yield stress | SDR |
|---|---|---|---|
| E0A0 | 72 | 270 | 3.75 |
| E0A1 | 138 | 270 | 1.96 |
| A12C12 | 65 | 270 | 4.15 |
| A25C26 | 129 | 270 | 2.09 |
| A26C26 | 57 | 270 | 4.74 |

（2）T+V：

| Pile | Axial load | moment | Initial yield moment | SDR |
|---|---|---|---|---|
| 1# | 2171 | 4846 | 7235 | 1.49 |
| 2# | 1634 | 5139 | 7088 | 1.38 |
| 3# | 1832 | 3972 | 7142 | 1.80 |

| Truss | Stress | Yield stress | SDR |
|---|---|---|---|
| E0A0 | 192 | 270 | 1.41 |
| E0A1 | 140 | 270 | 1.93 |
| A12C12 | 107 | 270 | 2.52 |
| A25C26 | 157 | 270 | 1.72 |
| A26C26 | 171 | 270 | 1.58 |

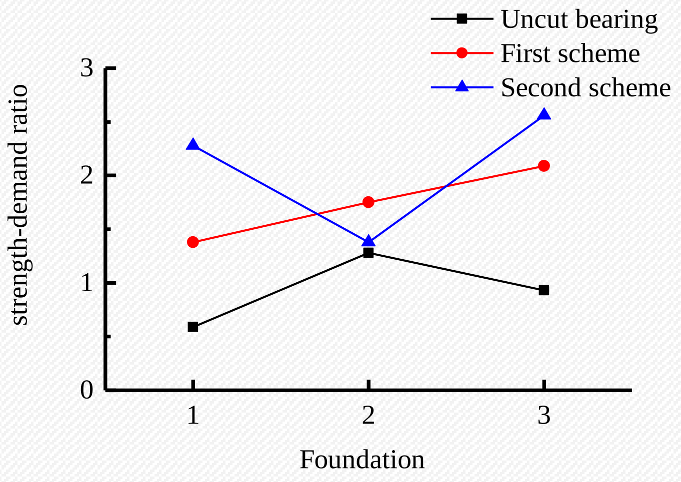
# 7、Comparisons of two schemes

- First scheme： Friction pendulum bearing (friction coefficient $\mu$=0.05, yield displacement $d_y$=0.0025m, isolation period $T$=3s).
- Second scheme： Cable-sliding aseismic bearing (friction coefficient $\mu$=0.02, yield displacement $d_y$=0.003m, free length $u_0$ =0.12m, horizontal stiffness of the cable $K_H$ = 15×10$^4$kN/m).

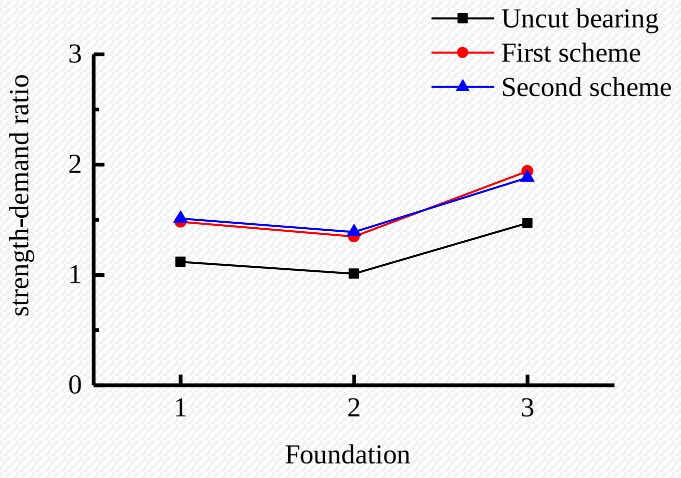
## ISOLATION EFFECTS UNDER E2 EARTHQUAKE：

Pile foundation： Compared to the condition with uncut bearings, two schemes can both reduce the seismic response, but the effects of the first scheme is more uniform than the second scheme, especially under L+V input.

L+V

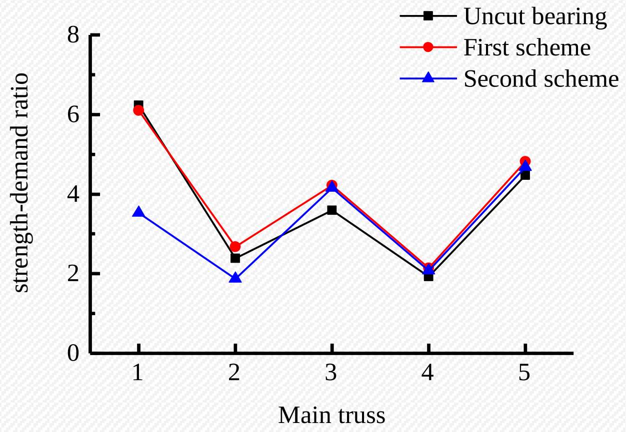



T+V

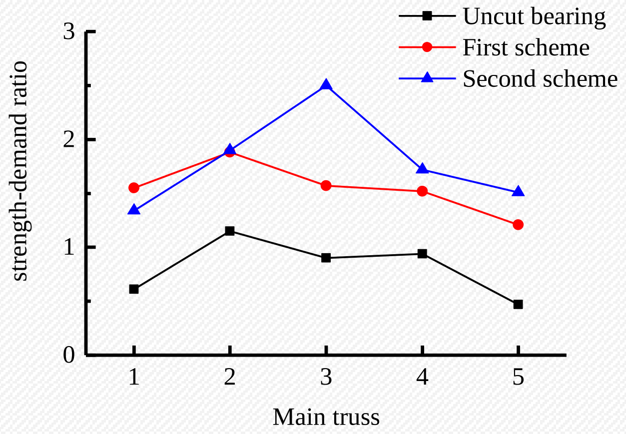


Main truss： Compared to the condition with uncut bearings, two schemes can effectively reduce the seismic response and increase the SDR of the key rods of the main truss, especially under T+V input.

L+V



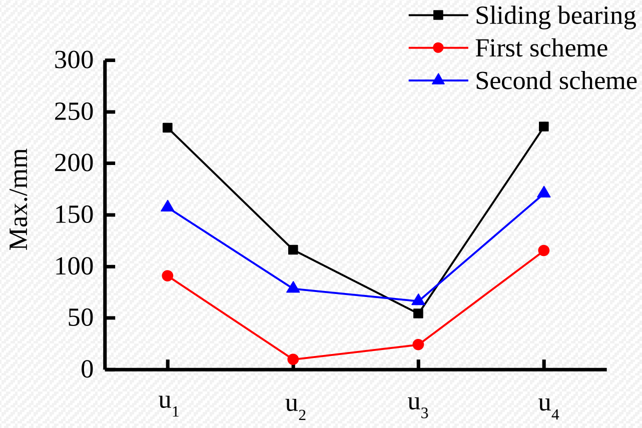

T+V



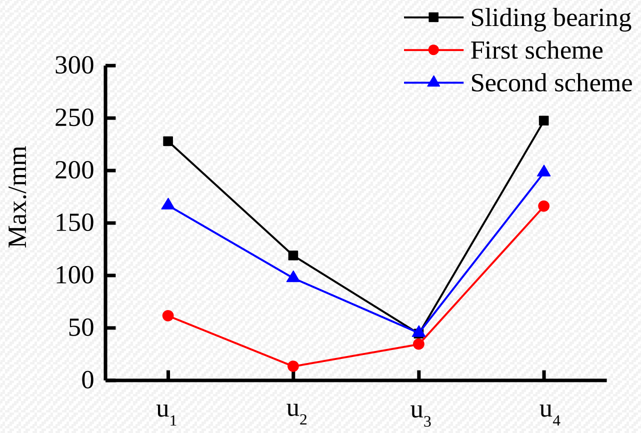

## ☐ SPACING EFFECTS UNDER E2 EARTHQUAKE：

Structural displacement： Compared to the condition with sheared-off bearings, two schemes can effectively control bearing deformations and structural displacements. But the friction pendulum bearing has greater self-centering ability, so structural displacements of the first scheme are smaller than the second scheme.

L+V




T+V



# Conclusion

- Considering the post-earthquake performance and the lack of ductile components, seismic isolation design is the best choice for the seismic design of the Songpu Bridge after widening and reconstruction.
- The friction pendulum bearings show great isolation effect with small structural displacements, but they are in complex stress condition, camplicated to be installed and comparatively expensive.
- The cable-sliding aseismic bearings use the free length to dissipate energy and the structural displacements are relatively large, but they are simple and cheap, easy to be installed and replaced.

# Thank you!

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