# Information on Seismically Isolated Continuous Girder Bridges

## 1. Project Overview

The bridge is a seismically isolated continuous girder bridge located in western China, with a total length of 100 m, consisting of five equal spans (5 × 20 m). Gravity-type U-shaped abutments with enlarged foundations are adopted to support the ends of the main girders, as shown in Figure 1(A). In addition, the bridge deck of the continuous girder bridge has a width of 10.4 m, and the main girder is a cast-in-place concrete box girder made of C40 concrete, with a height of 1.3 m. The relevant dimensional parameters are shown in Figure 1(B).

The continuous girder bridge has a total of four piers, all designed as circular reinforced concrete columns with C30 concrete. The elevation view is shown in Figure 1(B). Among them, Pier #1 and Pier #4 are double-column piers with a diameter of 1.2 m and a height of 7 m, with a center-to-center spacing of 5 m. Pier #2 and Pier #3 are single-column piers with circular cross-sections, 1.5 m in diameter and 9 m in height.

The main girder is connected to the bridge piers through bearings, and the bearing layout is shown in Figure 1(C). Among them, Pier #1 and Pier #4 use the same type of bearings with identical layout, while Pier #2 and Pier #3 use another type of bearings with the same layout.

## 2. OPENSEES Model

### (1) Nodes and elements

A three-dimensional model of the seismically isolated continuous girder bridge is established, with six degrees of freedom assigned to each node. The superstructure (main girder) is modeled using **elasticBeamColumn** elements, the bridge piers are modeled using fiber-section **dispBeamColumn** elements, and the bearings are represented by **zeroLength** elements.

### (2) Material Properties

**Confined and unconfined concrete:** In the developed bridge model, piers #1-#4 use confined and unconfined concrete, which are modeled using the Concrete01 material model in OpenSees. Detailed parameters including peak compressive stress ($f_{pc}$), ultimate compressive stress ($f_{pcu}$) and corresponding strains ($\varepsilon_0$, $\varepsilon_u$) are provided in Table 1.

**Table 1** Parameters of confined and unconfined concrete.

| | Ultimate compressive stress $f_{pcu}$ (MPa) | Peak compressive stress $f_{pc}$ (MPa) | Ultimate compressive strain $\varepsilon_u$ | Peak compressive strain $\varepsilon_0$ |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Confined concrete | 19.11 | 32.85 | -0.0036 | -0.0069 |
| Unconfined concrete | 14.52 | 17.09 | -0.0011 | -0.0040 |

**Longitudinal reinforcement:** In the developed bridge model, the longitudinal reinforcement in piers #1-#4 is modeled using Steel01, with yield strength ($F_y$), elastic modulus ($E_0$), and strain hardening ratio ($b$) specified. These parameters are provided in Table 2.

**Table 2** Parameters of longitudinal reinforcement.

| Yield strength $F_y$ （MPa） | Elastic modulus $E_0$ (GPa) | Strain hardening ratio $b$ |
|---|---|---|
| 381.65 | 200 | 0.01 |

**Lead Rubber Bearings (LRB):** The LRBs are modeled using **Steel01** to represent the combined behavior of the steel core, lead core, and laminated rubber layers. Detailed parameters are provided in Table 3.

**Table 3** Parameters of Lead Rubber Bearing (LRB)

| Yield Force $F_y$ (kN) | Initial Stiffness $k_1$ (kN/mm) | Post-Yield Stiffness $k_2$ (kN/mm) |
|---|---|---|
| 65.2 | 14.13 | 1.413 |

**(3) Fiber Section Discretization**

Fiber section parameters, including the number of fibers in compression and tension zones as well as the longitudinal steel layout, are provided in Table 4.

**Table 4** Parameters of fiber section.

| Pier | Outer radius $R_{out}$ (m) | Core concrete radius $R_c$ (m) | Longitudinal reinforcement radius $R_s$ (m) | Number of longitudinal bars | Cross-sectional area of longitudinal bars $A_s$ (mm$^2$) |
|---|---|---|---|---|---|
| Pier 1# and 4# | 0.600 | 0.565 | 0.530 | 28 | 490.9 |
| Pier 2# and 3# | 0.750 | 0.710 | 0.670 | 40 | 490.9 |

**(4) Modeling Assumptions and Nonlinear Behavior**

1) Distinction between confined and unconfined concrete captures the strength enhancement and ductility due to transverse reinforcement.

2) LRB bearings and reinforcing steel employ typical elastoplastic models to simulate hysteretic behavior.

3) The main girders are not expected to experience significant plastic deformation under seismic loading; therefore, they are modeled using elastic elements.

**(5) Seismic Excitation and Analysis**

1) The bridge is subjected to a uniform ground motion input along the longitudinal direction.

2) Transient analysis is performed using the Newmark integrator ($\gamma = 0.5$, $\beta = 0.25$), Newton-Raphson algorithm, and NormDispIncr convergence test (1e-3, 100 iterations).

3) The ground motion is applied for 5100 steps with a time step of 0.02s.

4) Damping is represented by classical Rayleigh damping, with a 5% target damping ratio assigned to the first two modes to approximate energy dissipation.

**(6) Modeling and Analysis Procedure**

**1) Modeling process**

In this model, the nodes of the bridge girder, piers, and bearings are first defined and assigned masses to accurately represent the dynamic characteristics of the structure. Next, the material properties and cross-sectional attributes are specified to provide the fundamental mechanical parameters for the element analysis. Subsequently, beam elements are generated through geometric transformation and assembled according to the structural layout to form the complete bridge system. Finally, boundary conditions and node connections are defined through constraints and linking elements to ensure that the behavior of bearings, beam ends, and additional components is correctly simulated, enabling an accurate analysis of the overall structural performance.

**2) Analysis process**

First, the natural frequencies of the structure's first two modes are calculated, and the corresponding Rayleigh damping coefficients are determined and applied; next, the seismic input is defined, and the acceleration time histories are applied to the structure in the specified direction; then, recorders for nodal and element displacements, forces, and curvatures are set up to extract time histories and extreme responses; afterward, constraints, numbering, solution system, convergence criteria, nonlinear solution algorithm, and integrator are configured; finally, a transient dynamic analysis is performed to obtain the structural response under seismic excitation.

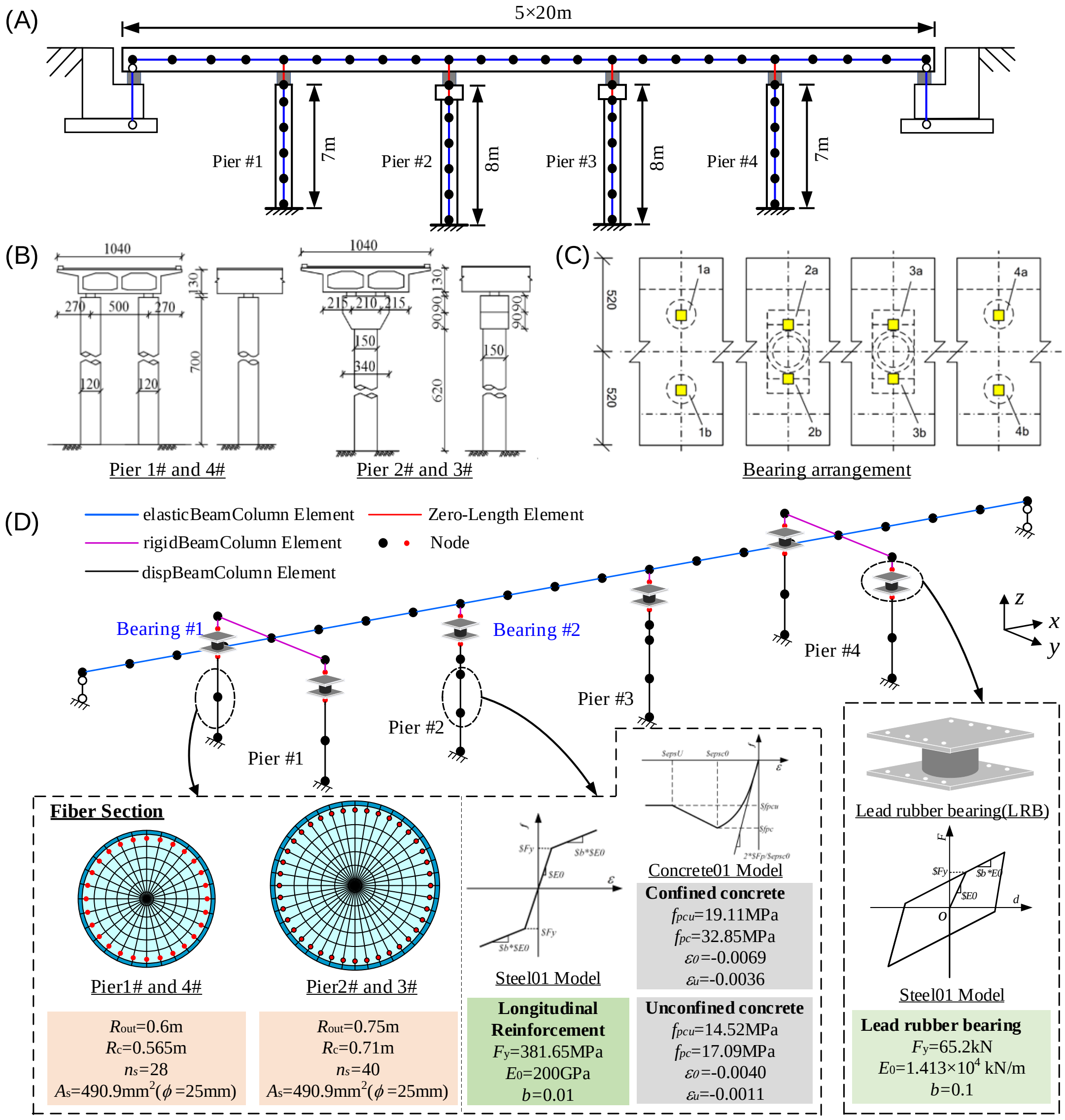


**FIGURE 1** Layout and FE model of the isolated continuous girder bridge.