# Composite Bridge Design and Pile Freeze Back Test in Cold and High-Altitude Permafrost Regions

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**ABSTRACT**

After sixty years service of Qinghai-Tibet Road, highway joining Golmud and Lhasa was about to build. The design scheme for bridge constructed in cold and high-altitude environment needed to be analyzed. Given the complicated geological and ecological conditions plus high seismic-risk, steel-concrete composite bridge was recommended. An integral concrete-steel composite girder (ICG) scheme for permafrost region application was proposed, whose highlights mainly included mill-fabrication, overall-girder-erection, fast construction, less labour consumed by cast-in-situ. Field test for pile freeze back in permafrost region was carried out to investigate the solid bond formation time. Freeze back test was in the backdrop of the construction of Chala Ping Bridge. Pile freeze back field test could be a practical reference for the small-span bridge construction schedule drafting in permafrost region.

**KEYWORDS:** composite bridge, steel I girder, permafrost region, frozen ground, pile freeze back.

## 1 INTRODUCTION

In cold and high-altitude permafrost region such as Kunlun Mountains in Tibet, compared with bridge construction in general, harsh environment, hypoxia, slow and high cost of logistics supply these factors made bridge construction a big challenge. Bridge in the permafrost intended to settle non-uniformly, which made simply supported structure a best choice to resist the deformation (Zhang J.Z., 2001). Recently a lot of researches were concentrated on the interaction of pile foundation and frozen ground (Yu D.Z., 2016). Cast-in-place piles were widely used in cold region structures (Jiang D.J., 2016). It should be left enough time for the pile to bear load after pouring, which is mainly dominated by the time when surrounding frozen ground freeze back and an adequate frozen bond between pile and soil formed. At the mean time, both traditional and novel composite bridges were popular in general infrastructure design in China (Xiong Z.H., 2015).

In the following content, bridge superstructure and substructure applied in permafrost and high-altitude region were investigated respectively. On superstructure an integral girder schematic design was proposed. On substructure, pile freeze back field test was carried out to make the appropriate construction schedule.

## 2 INTEGRAL COMPOSITE BRIDGE FOR COLD REGION APPLICATION

Highway linking Golmud and Lhasa (part of National Highway G6), most route site was located in high-altitude plateau. The route went through ten active faults including Kunlun Mountains Active Fault, Kekexili Active Fault .etc. In the high seismic risk zone, steel bridge was prevailed than prestressed concrete (PC) bridge in terms of light weight, while the traditional orthotropic steel deck fatigue crack in the U rib was a main retrofit item. (Samol Y., 2010). Instead of orthotropic deck concrete slab was a good solution either in durability or cost. Given the crucial condition of Qinghai-Tibetan Plateau, the current construction method requested a high demand for the construction worker, in which concrete slab was placed after the installation of steel girder. According to the special construction environment, an integral composite girder scheme was proposed. The integral composite girder (ICG) was fabricated in shop in a whole, the concrete slab was cast in shop after the completion of the steel part. ICG was transported in whole to the site. After lifting the ICG in position, the lateral brace was then installed, longitudinal cast-in-situ construction gap was poured.

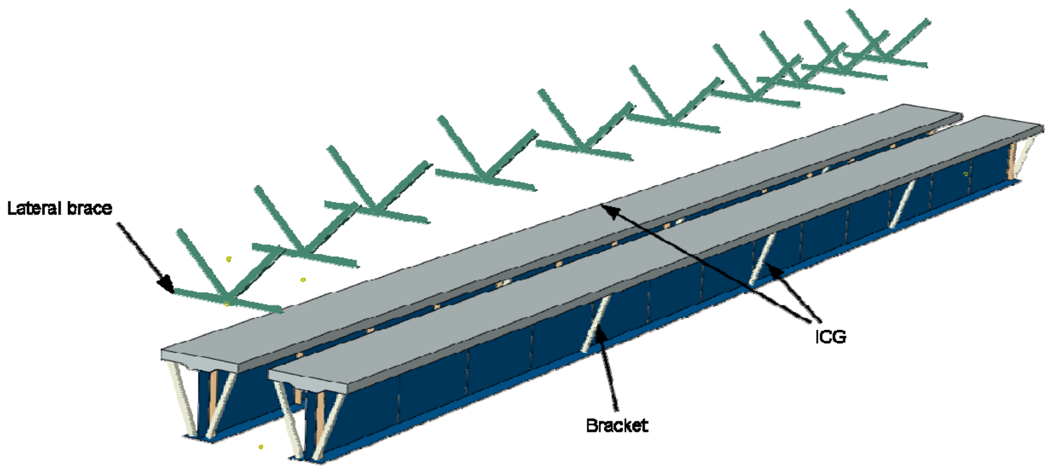


Figure 1: ICG construction demonstration

The advantage of ICG includes: 1) minimum labour in site and fast construction, 2) fabrication quality guaranteed by shop, 3) minimizing the probability of concrete deficiency dominated by extreme weather. The overall structural analysis was carried out to further the knowledge of ICG performance in the next chapter.

## 3 STRUCTURAL ANALYSIS OF INTEGRAL COMPOSITE BRIDGE

### 3.1 Structural Design

Overall width of bridge deck was 13m, layout of girder was shown in Figure 2. In this paper 30m-span and 40m-span were analyzed. The plausible depth of girder was given as 1.6~1.8m and 1.3~1.5m for 40m-span and 30m-span respectively. Web thickness was 20mm. Top and bottom flange widths were 500mm and 800mm respectively. Concrete slab was made of C50, the thickness varied from 220mm to 370mm. Two adjacent ICG was left a longitudinal construction gap. Completing the installation of lateral brace, the longitudinal construction gap was then casted.

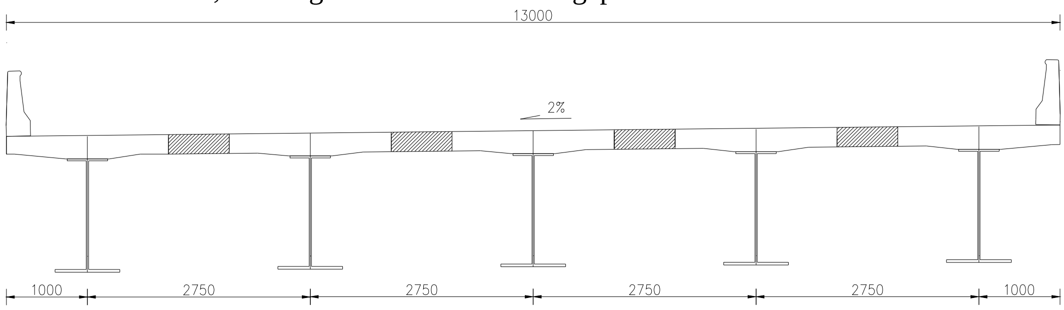


Figure 2: Girder Layout

During the fabrication and construction stages, torsional effect was formed which could result in slab crack in the cantilever in extreme circumstances. Overhang bracket should be set at intervals, which provide solid support and stability for ICG. Concrete slab reinforcement ratio was 0.9%. For ICG, since compression was relatively small, transverse stiffener was built at 2~3m interval on the web.

### 3.2 Structural Analysis

Bridge structural analysis model was built by CSIBRIDGE, in which steel girder web and concrete slab were simulated as shell element and lateral brace was modelled as beam element. Use of shell elements for the slab and I-girder web, beam elements for the I-girder flange was validated and sufficient for nonlinear simulation of the experimental result (Ching J.C., 2008). Live load and temperature gradient was input according to Chinese provision. Substructure was simplified as a stiffened spring. Two combinations were applied to the model including Ultimate Limit States (ULS) and Serviceability Limit States (SLS). Deflection was obtained under the live load regardless of braking effect.

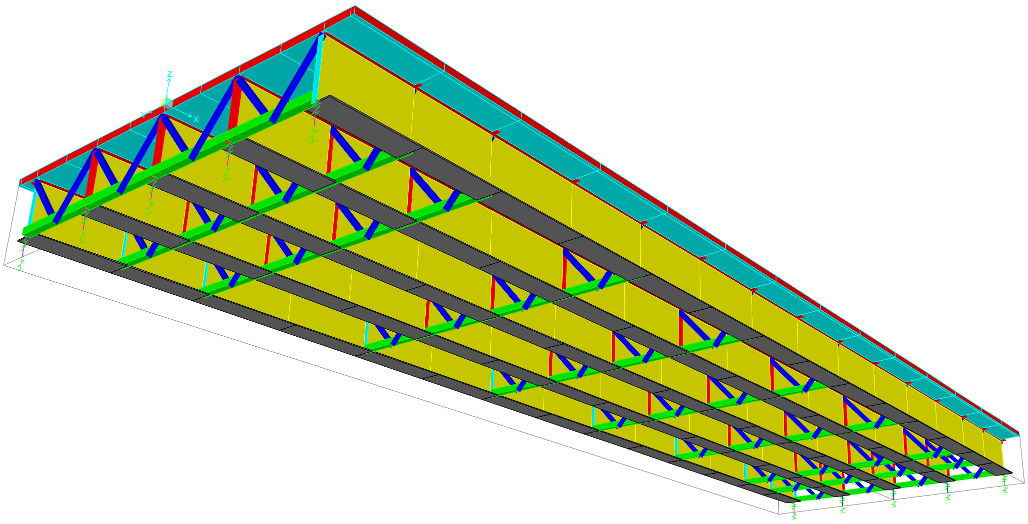

Figure 3: ICG Bridge FEM 3D View

The results of two combinations were listed in Table 1 and 2. It was found that the ULS was the governing combination for ICG. Given the allowable stress in Chinese code for Q345D, a design strength efficiency ratio was defined as:

$$k_e=\sigma_{max}/\sigma_k \qquad (1)$$

Table 1 40m-span ICG Resultant

| Girder depth (m) | Ultimate Limit States | | Serviceability Limit States | | Deflection (mm) |
|---|---|---|---|---|---|
| | Moment (kN m) | $\sigma_{max}$ (MPa) | Moment (kN m) | $\sigma_{max}$ (MPa) | |
| 1.6 | 6847.2 | 250.5 | 4399.4 | 155.0 | 38 |
| 1.7 | 7267.3 | 248.0 | 4659.5 | 151.6 | 37 |
| 1.8 | 7587.6 | 238.4 | 4872.9 | 145.3 | 35 |

Table 2 30m-span ICG Resultant

| Girder depth(m) | Ultimate Limit States | | Serviceability Limit States | | Deflection(mm) |
|---|---|---|---|---|---|
| | Moment (kN m) | $\sigma_{max}$ (MPa) | Moment (kN m) | $\sigma_{max}$ (MPa) | |
| 1.3 | 4256.5 | 279.6 | 2682.4 | 167.4 | 33 |
| 1.4 | 4402.9 | 254.0 | 2796.2 | 153.0 | 27 |
| 1.5 | 4489.0 | 226.3 | 2880.0 | 138.2 | 22 |

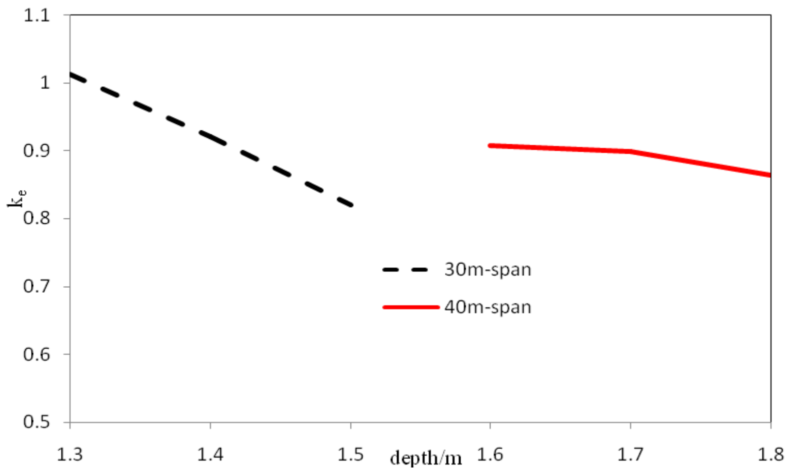


Figure 4: Relationship between Strength Efficiency and Girder Depth

As observed from Figure 4, girder depth range 1.4~1.5m for 30m-span was appropriate. For 40m-span, the appropriate girder depth range was 1.6~1.7m considering a balance between the safety and cost efficiency. For concrete slab, crack width was within the allowable value.

## 4 PILE FREEZE BACK FIELD TEST

It is found that the bearing capacity of the pile buried in the permafrost is mainly governed by the frozen bond between soil and pile (Orlando B. A., 2004). As a result, the freeze back time needs to be investigated to draft the construction scheme of superstructure. Pile freeze back field test was carried out in Gong Yu Road Reconstruction Project in Qinghai. The site soil was mainly composed of permafrost, permafrost natural table was 0.7～1.6m , thaw-settlement classification was Ⅰ～Ⅴ. The mean annual ground temperature was -0.3～-1.8$^{0}$C. The soil can be classified into 4 layers. They were listed as:

(1) Sod, a thickness of 0.8m, highly compressive;
(2) Ice with mud (Q4al+pl), a thickness of 3.2m, silt, about 60% of Volumetric Ice Content(VIC) ;
(3) icy soil (Q4al+pl)，a thickness of 7m, pebbles, about 15% VIC;

(4) ice-poor frozen soil, a thickness of 20m, weathering of mudstone, about 5~9% VIC.

### 4.1 Temperature sensor arrangement

Pile freeze back field monitoring was chosen on Chala Ping Bridge, which was a continuous PC bridge and part of Gong Yu Road Reconstruction Project. The pile was cast-in-place and its diameter was 1.5m. Multiconductor cables containing several temperature sensors were inserted in the borehole. The measurement depth was depicted in Figure 5. From ground surface to 10m depth, the temperature sensor interval was 0.5m. From 10m to 20m depth, the sensor interval was 1m. From 20m to 32m depth, the sensor interval was 2m. Two main data-acquisition systems with shelter were installed to record the data.

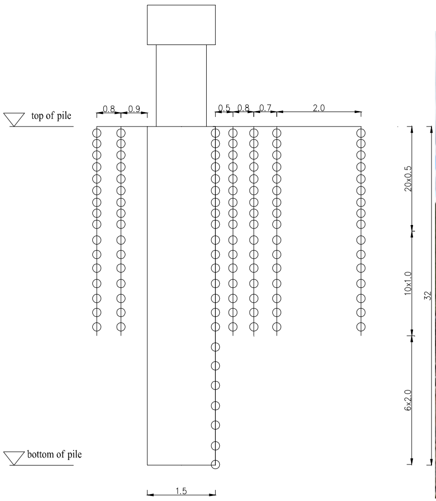


Figure 5: Sensor Setup in Borehole    Figure 6: Multiconductor Cable Insertion

### 4.2 Test result

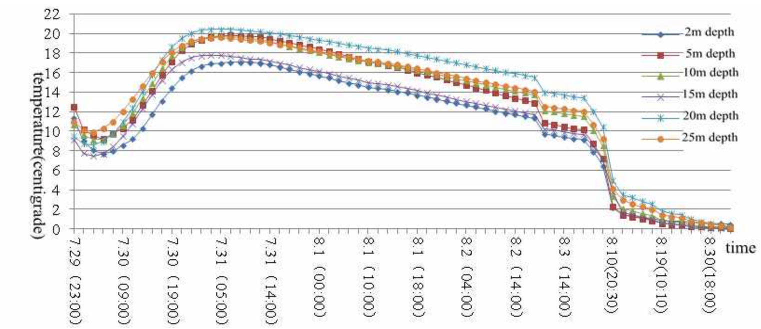


Figure 7: relationships between pile-soil interface temperature and borehole depth

Figure 7 demonstrated ground temperature of six different depths from 2m to 25m below ground surface. It was shown that exothermic process last 34 hours until the temperature reached the peak. It took almost 10 days for temperature descending 80% of the peak temperature. In about 30 days, ground temperature near the pile decreased to 0 $^{o}$C .

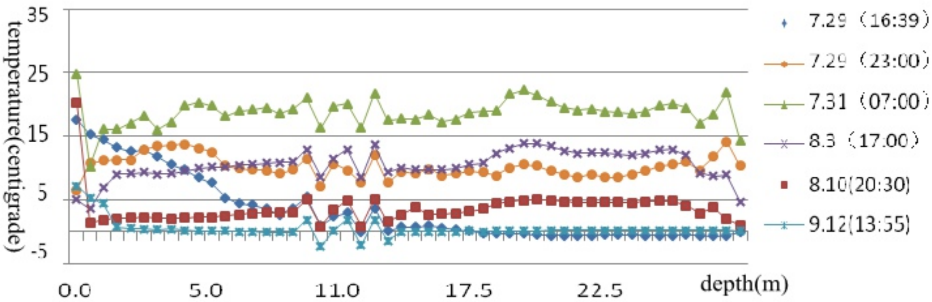


Figure 8 Pile-Soil Interface Temperature-Time curves

It was observed in the initial 34 hours ground temperature reached the peak as presented in Figure 8. In depth 5-30m below the ground, maximum ground temperature near the pile was about 20 $^{o}$C. After 45 days cooling, ground temperature degraded to 0 $^{o}$C.

## 5 CONCLUSIONS

Integral composite girder bridge scheme for cold region application is proposed in this paper. By parametric analysis of ICG overall performance, it has been found a reliable solution in terms of construction efficiency and structural safety. In a balance between structural safety and project cost, the appropriate ICG girder depth range is 1.4~1.5m and 1.6~1.7m for 30m-span and 40m-span respectively. Local stability of ICG during construction could be enhanced and assured by temporary bracket. Pile freeze back field test has been carried out in Qinghai permafrost region. For the pile freeze back time prediction of small-span bridge built in permafrost region, the freeze back test in this paper provide a reference for those piles with diameter no larger than 1.5m.

## 6 ACKNOWLEDGEMENTS

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