NON-GAP DESIGN METHOD AND TEST FOR POST-TENSIONED PRESTRESSED R.C. STRUCTURE

Li Lijuan[1,2], Liu Feng[1], Fu Ganqing[1], Lu Weiwen[1]
[1]Faculty of Construction Engineering, Guangdong University of Technology, 510643, China
[2]Department of Civil Engineering, The University of Liverpool, Liverpool, L69 3GQ, UK

Summary: A non-gap design method is introduced, which includes using post-poured concrete strips, cold-rolled ribbed welded steel grids and post-tensioned pre-stressed concrete beams. The purpose of the method is to resist cracking in the slabs of the Shenzhen Tian Digital Mansion (in Shenzhen, China), a long span new building. The method was used despite the general requirement for setting gaps in slabs exceeding 40m long in the Chinese code of practice. The design is based on maintaining the concrete slab strain within the specified limits required by the Chinese code at all stages in its life. One purpose of the test is to confirm that the concrete strain is within the desired limits and the other is to see if the stress can be transferred to slabs evenly from beams, as expected. The stresses in the slabs have been tested for one year to determining the stress distribution and the corresponding strains. The test was carried out before the pre-stress was applied and lasted for one year after pre-stress construction finished. The stresses and their variations on different slabs and at different locations were measured. Test results showed that the strains met the requirements of the code of practice and the new design technique used in this new building is effective and can be extended to the design of similar structures.

INTRODUCTION

With the application of pumping-concrete and high strength concrete in super long reinforced concrete structures, it is easy to cause temperature cracks [1,2]. In order to control the flexural, thermal and shrinking cracks, a new design and construction method has been introduced. Cold-rolled ribbed welded steel grids with high strength than mild steel are used in the slabs of the structures. Post-tensioned pre-stressed strands are employed in the longitudinal beams, so that the floor slabs can obtain pre-stress from them. Furthermore, for reasons of economics, pre-stressed tendons are used only in some floors of the structure. The test lasted 12 months to confirm the efficiency of the design method. Stress test readings were recorded from the 22nd to the 26th storey as well as at the roof, with pre-stress tendons used only from the 24th to the 26th storey and at the roof. Stress and temperature, as well as their variations at the different testing points, are given in this paper. The stress variations at different testing points on the different floors are compared. The effects of the temperature variations on the stresses in the slabs are also investigated. Strains in the different floors were also obtained during the test. The strain results show that the design method adopted in this project is feasible and efficient and can be extended to the design of similar structures.

METHOD OF RESISTING CRACKING IN SUPER LONG SLAB

Post-poured strips

Two post-poured strips are set symmetrically in the floor construction, which divides the floor slab plane into three parts. Each part is about 40m long. Concrete with slightly expansive property was used in the post-poured strips to decrease shrinkage and creep deformation.

Cold-rolled ribbed welded steel grids

The excellent crack-resisting ability of welded steel grids has been demonstrated in roads and bridges. For this reason, cold-rolled ribbed welded steel grids with higher strength (f_y=360N/mm^2) than mild steel (f_y=210/ mm^2) were used in the slabs of the structure. This arrangement not only resulted in savings in steel quantity, but also the effects of shrinkage and creep were reduced. The steel grids were ideally suited for factory production, where large numbers of identical units could be economically made under controlled conditions and were easily installed on site. Conventional reinforcements were still used along the lengths of the slabs, which reduced the deformation of the slabs. The arrangement provided a very convenient, efficient, and economical design.

Pre-stressed tendons

Since large temperature differences can exist between the two surfaces of the roof, which will cause and accumulate temperature stress, un-bonded pre-stressed tendons were used to control structural cracking. The pre-stressed floors are shown in Figure 1. Post-tensioned tendons were located in the beams of the floors from the 24th to 26th storeys as well as in the roof. They are in the longitudinal direction. The tensioning sequence was as follows: tension the tendons that are in the beams of left and right parts of the floor slab first and then tension those spanning the post-poured strips.

TEST METHOD AND ARRANGEMENT OF TEST POINTS

In site test, model GGH-10 (with diameter 10 bar) stress sensors and model GSJ-2A digital monitor are used as in [5,6]. Considering the structural symmetry, all 8 of test points were arranged in one half of the floor. The test points labeled 'S' in Figure 2 sum to 48 (6 levels with 8 points each). All the steel stress sensors were embedded along the longitudinal axis of the floor. Temperature sensors were also embedded to test temperature variations in the slabs. 4 temperature sensors (labeled 'T' in Figure 2) were embedded in the 26th floor and 3 in the roof.

ANALYSIS OF THE TEST RESULTS

Stress variations in different floors

The stress values at the different test points, both before (11/09/2002) and after the tendons were tensioned, are presented in Figure 4. The stress changes along the length of the two different sections are given in Figure5.

It can be seen from Figure 4 that the stress variations at the different test points on the same floor are similar, as are those for similar points on different floors. The maximum stress difference is 70MPa, which happened on 26th floor. The maximum on other floors is about 40MPa. The test results show that most of the concrete stresses are compressive. Tensile stress occurs only in the tensioning period of pre-stress and the maximum tensile stress obtained is 13.8MPa. We can conclude from Figure 5 that, in the same section, the magnitude of the stress level and the stress changes in the floor with pre-stress are similar to those of the floor without pre-stress. The stress level in the longitudinal direction of different floors is even.

Effect of the pre-stressed beams on slabs

The compressive stresses in the floor change periodically for the different test points, which agree with the condition that pre-stressing occurs periodically. The compressive stresses in the floor do not change periodically after all the tensioning is finished but increase slowly with time. The reason is that there exists a time lag between the pre-stress in the beams and in the slabs. Pre-stresses are transferred from beams to floors slowly.

Although it is difficult to have a separate quantitative analysis of the effects that influence thermal stresses in the floors, the comprehensive stress variations from the test readings show that the mean stress difference in the floor reinforcement is about 40MPa, which is acceptable for steel grids. The maximum tensile stress of steel in the slabs is 13.8MPa and the corresponding tensile strain is 69µs.Thus the tensile strain in the concrete is also 69µs, with the steel and concrete stresses being related by the compatibility of strain across the section. This value is less than the ultimate tensile strain value for concrete, being 80µs.

Temperature variation of ambient and floors

The temperature variations at the bottom, the middle and the upper surface of the 26^{th} floor and at the roof, as well as the ambient temperature, are shown in Figure 6. During the 12-month testing, the maximum temperature difference was 20.2^{o}C outdoors and 17.4 ^{o}C indoors; the corresponding mean temperature difference was 4.7 ^{o}C and 3.4 ^{o}C, respectively. As expected, the temperature variation indoors was smaller than that outdoors, showing that the thermal insulating layer used in the roof worked efficiently and decreased the stress in the concrete, and helping to control cracks in the floors.

CONCLUDING REMARKS

(1) Steady and even pre-stresses in concrete floors can be obtained by tensioning tendons in beams. Thus, concrete floors can be maintained in a state of compression throughout, providing resistance to thermal cracking.
(2) The maximum test stress variation in un-pre-stressed steel is about 40Mpa, which is acceptable for conventional reinforcement.
(3) In a high building, the roof and upper floors (4 floors near to top) are the locations most sensitive to temperature variations and needing appropriate reinforcement methods.
(4) Cold-rolled ribbed welded steel grids can reduce concrete deformation, the chance of cracking, and the amount of steel used in floors. It proved to be a very convenient, efficient and economical material for buildings.
(5) Tensioned tendons used properly in some important parts of a building can produce good enough results even if it is not so good as that of the whole building is used.

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