Analysis of Box Girder Cracks on PC Bridge

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Abstract. PC bridges with box girder has been built a lot for recent years, but an outstanding problem is exposed in most built PC bridges with box girder--cracks during the process of construction and operation, which do great harm to the normal use, safety and durability of bridge. This paper analyses the main reasons for the box girder cracks on PC bridge completely and puts forward responding advice to solve this problem which is meaningful to the maintenance, design and construction of PC bridges with box girder.

Introduction

PC bridge has been built greatly recent years due to their many advantages, such as aesthetically pleasing compact design, integrity, continuity, full-fledged construction technology and design theory [1]. The girder mainly adopts box section for its great bending stiffness, torsional stiffness and low girder height and the PC bridge with box girder has many construction methods, such as cast-in-place, cantilever pouring, prefabricated, pushing, sliding cross cast-in-place. The PC bridge with box girder has less seam, which is comfortable for driving and also easily maintained, and the creep deformation is smaller than T beam. However many problems have been exposed and what the most common is the different cracks in the roof, floor, web, diaphragm and gear block during the process of construction and operation which are harmful to the durability, safety and normal use of bridge[1]. Therefore, it is meaningful to analyze the main reasons for the box girder cracks on PC bridge in the round and puts forward responding advice to solve this problem.

Defection in Design

External forces acting on the box girder can be comprehensively expressed as eccentric load for structure analysis, box girder will produce the combined deformation of bending, torsion, distortion and lateral deflection as well as the shear lags effection in vertical bending under eccentric load. Continuous rigid frame bridge and continuous girder bridge adopt the plane linkage program during the design and calculation. This analysis software for the overall analysis of continuous rigid frame bridge and continuous girder bridge is a simple and effective method, but this kind of design calculation method cannot accurately considering the influence of shear lag effect and he distortion actually existing in the box girder. In the overall analysis, the local fine analysis of section model on the basis also has deviation because of similar boundary conditions. Although some calculation software can consider the effection of shear lag effect, torsion, distortion and lateral deflection on structure, it is not widely applied in practice for the complexity of modeling and the clearity of calculation results. There are also many designers tadopting some new computing model to design the box girder bridge, but the inconsistency problem between the computing model, simplified assumption and practical stress state result in structure engineer's inaccurate grasp on the box girder stress.

The improper layout of longitudinal prestressing will cause the longitudinal flexural cracks on the bottom plate of mid-span section and top plate of pivot section, and the principal tensile stress of box girder webs which result in inclined cracks; unreasonably setting or loss of vertical prestress

will cause the principle tensile stress of box girder webs which result in inclined cracks; the improper layout or tensioning tonnage of transverse prestressing on the top plate will cause tensile stress which results in transverse bending cracks in bridge near the midline due to the insufficient ability to resist tensile stress.

The size of the box section directly affects the ability of structure resisting load and decides the crack emergence and expansion of box girders. Therefore, a reasonable size should be determined to ensure the safety of structure. Low girder height can reduce the force of structure caused by dead load , but the low girder height will increase difficulties of prestressing arrangement and the loss of prestress, reduce the effective prestress which results the failure of the box girder webs due to the principle tensile stress. Web stress includes normal stress on positive section, direct shear stress, incidental normal stress and shear stress caused by the shear lag and distortion, stress caused by vertical prestressing stress and the shear flow caused by torsion of box girder which all affect the principal tensile stress of web and the web thickness affects the principal tensile stress value of box girder web.

In general, the defection in design of the structure is mainly reflected in the following aspects: none calculation or missed calculation, the unreasonable calculation model, the inconsistency between the assumpted structure stress and actual stress, the error in force and reinforcement calculation, the structure safety factor is not enough, designer don't consider the possibility of construction, girder height too low, the improper or less layout of prestressing, insufficient rigidity of structure, improper handling etc.

Temperature Stress

When the temperature rises to 60-100 degree, free water in the concrete will be evaporated greatly for the effection of high temperature environment and hydration heat during the construction of large volume concrete, which results in the cracks. When the temperature is above 150 degree, cement will shrink and aggregate will expand, which results in the bond between the cement and aggregate being gradually destroyed and the emergence of cracks [2].

This kind of additional stress and the original load stress superpose resulting more serious cracks in the members. In the box girder bridge, bridge deck, the main girder or pier side after being tanned by the sun, the temperature was higher than other parts, the temperature difference of box between inside and outside is very big and the temperature gradient is distributed nonlinearly. The cracks will emerge in box girder due to large local tensile stress caused by self-restraint. Sunshine and the sudden drop in temperature are the most common causes of structure temperature crack. It can be found that the temperature difference effection of structure system on the force (stress) of superstructure in box girder bridge accounts up only 5% of the effection caused by the dead load, while the effection of the sunshine temperature difference on the force (stress) of structure is much bigger than effection caused by the system temperature difference which results in large local tensile stress and the temperature cracks in some parts of box girder through calculation. The main factors causing temperature cracks are as following:

(1) Temperature difference between years. The temperature changes all the year, but change is slow.

(2) Sunshine: The temperature of the bridge deck, main girder and pier side is higher than other departments after being tanned by the sun and the temperature gradient is distributed nonlinearly. The cracks will emerge in box girder due to large local tensile stress caused by self-restraint. Sunshine and the sudden drop in temperature are the most common cause of temperature crack in structure.

(3) Sudden drop in temperature. Dumping heavy rain, cold air attack and sunset may make structure surface temperature drop suddenly, but the inside temperature change relatively slow which resulting in temperature gradient.

(4) Hydration heat. Large volume concrete (thickness more than 2 m) releases heat after pouring due to cement hydration, which makes the internal temperature very high (up to over 70 degree)

and large temperature difference between the internal and external resulting in surface cracks during the construction process.

(5) Concrete construction measures are improper in steam curing or winter construction, cold-sudden fever concrete and the temperature difference between inside and outside will create cracks easily.

Concrete Shrinkage and Creep

Another important factor causing cracks is creep and shrinkage of concrete. From the impact of shrinkage and creep of concrete on the force of structure, its effect is self-adaptive adjustment process of the structural deformation and stress distribution, after stress redistribution, the force of structure tends to be more reasonable. But for prestressed concrete continuous girder bridge, shrinkage and creep of concrete will cause the change of prestress at the same time and prestress in certain parts of the structure appears insufficient, which causes cracks in box girder due to large local tensile stress.

Concrete creep is nonlinear deformation which depends on the load and relates to time. The free water in the cement gel from the capillary tube is extruded and evaporated in concrete under long-term load, which causes the cement colloidal volume reduced and the deformation of concrete [3]. The influence of concrete creep on concrete structure has both advantages and disadvantages. For large volume concrete, concrete creep can reduce the temperature stress caused by the hydration heat. For prestressed concrete continuous girder bridge, creep can increase prestress loss, reduce the effect of prestress, increase the structure deformation and cause the stress redistribution of bridge structure, which causes cracks in box girder due to large local tensile stress.

Foundation Deformation

Because of the uneven vertical settlement or horizontal displacement of foundation, the additional stress generated in the structure, even beyond the tensile capacity of reinforced concrete structure which makes the structure crack.

Construction Factors

During the process of pouring, moulding, transporting and installation of concrete structure, if the construction techniques is unreasonable and the quality of construction is poor, different kinds of cracks will generate.

Due to the improvement of strength grade of concrete and the requirement of pumping concrete, the amount of cement and sand ratio increase, aggregate size decreases which makes the heat of hydration and shrinkage of concrete increase. The casting temperature is too high, the temperature difference between inside and outside is too large and the strength of concrete is low, which causes cracks in the concrete surface easily.

None precise measurement for various components is made during the process of the concrete mixing which makes the actual gradation have deviation from the theory value, quality control of fine and coarse aggregate is not strict and the volume of mud is high, which results in that concrete strength is lower than the design value. Skeleton reinforcement bars are relatively great in continuous prestressed concrete bridge with box girder, difficult construction, installation position of the framework reinforcement and the fabrication and installation of stirrup are difficult to satisfy the design requirements. Many reinforcement skeleton and small space in web cause that it is difficult for internal concrete to vibrate, which makes the concrete strength lower than the design strength and anti tensile strength also decrease.

The templates and brackets that some construction units select don't have enough stiffness, which results in large deformation of brackets when pouring concrete. If the web brackets are removed early, the temperature difference between the inside and outside is too large and concrete is not maintained timely, the web will crack.

Other reasons, such as the mechanic model of structure changing and the construction equipment was being stacked on the bridge freely during the construction process, will change the force state of the bridge at construction phase, which will increase the local stress and cause cracks on bridge.

Material Defection

Concrete is mainly composed of cement, sand, aggregate, mixing water and additive composition. If the material quality composed of concrete is not satisfied the requirement, the structure will crack.

The material problems have many aspects. Cement stability is unqualified. If the strength of the cement is not enough or it is damped and expired, the strength of concrete will become insufficient. When alkali oxide contents in cement is great (more than 0.6%) and the sand, stone aggregate with alkali activity is contained at the same time, the alkali aggregate reaction will happen.

If the particle size, gradation, impurity content of sand, stone aggregate is unreasonable, the strength of concrete will be decreased and the shrinkage of concrete will increase, if fine sand which is smaller than the prescribed extra fine sand is used , more serious consequences will happen.

Problems in Concrete Stress Limit Value

A lot of research about the above factors affecting the cracks of structure have done at home and abroad, some achivements are attained have been applied in the actual design. But the stress limit value of the concrete box girder under multi-dimensional stress state has not researched. The strength of concrete given in chinese codes is the strength under uniaxial stress [4]. In fact, in many of the reinforced concrete structures, such as reinforced concrete two-direct slabs supported on four sides, two-direct or three -direct prestressed concrete bridges, the concrete is multi-dimensional stress state. Tests prove that the strength and deformation property of concrete under multi-dimensional is different from them under the uniaxial stress state.

Conclusion

This paper analyses the main reasons for the box girder cracks on PC bridge completely, the main reasons include defection in design, temperature stress, concrete shrinkage and creep, foundation deformation, material defection and problems in concrete stress limit value. The crack mechanism of each factor is researched carefully. Responding suggestions are put forward for bridge engineer to solve this problem which is meaningful to the maintenance, design and construction of PC bridges with box girder.

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