Behaviour of Tendons for Cryogenic Applications

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Summary

When designing LNG tanks also accidental load situations like overfilling the tank beyond the specified limit have to be considered. In conjunction with overfilling leakage of the inner tank or total failure of the inner tank the surrounding members will be subjected to a thermal shock. Therefore, among other things special investigations on the tendons are necessary. Sufficient resistance against static load at cryogenic conditions can be guaranteed by tests on the prestressing elements and by single tests with anchorages and tendons. Especially the single tests at cryogenic conditions shall be repeated for every LNG tank to guarantee similar behaviour of the strands and wedges used in the specific project. By requiring ductility criteria for the strands without anchorage as well as for the anchored strands brittle failures can be avoided.

Keywords: LNG, tank, prestressing steel, post-tensioning, tendon, cryogenic condition.

1. Introduction

Usable energy is the mainstay of our contemporary way of life and culture. At present, the fossil fuels coal, oil and natural gas are the backbone of the European and global energy supply. According to the Kyoto Protocol flaring of manufactured gases shall not be tolerated furthermore. Tanks for liquefied natural gas (LNG) are built all over the world. The full-containment-tanks consist of steel-liners that are surrounded by an outer prestressed concrete tank.

In conjunction with overfilling leakage of the inner tank or total failure of the inner tank the surrounding members will be subjected to a thermal shock. Therefore, among other things special investigations on the tendons are necessary.

2. Construction principle of LNG-tanks

The LNG with a temperature of -164° Celsius is stored in the steel tank. The outside concrete tank is protecting the inner steel tank against outer actions and is acting as retention basin in case of leakage of the inner tank. Tank dimensions are up to 90 m in diameter and 50 m in height with a wall thickness in the order of 750 mm. The post-tensioning tendons are very large and can run in both the vertical and horizontal direction.

3. Properties of Prestressing steel and Tendons at cryogenic conditions

In case of overfilling it has to be kept in mind that the mechanical properties of concrete, reinforcing steel and tendons are differing between normal conditions (room temperature) and -164°C. In the following main focus is laid on the tendons.

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Usually for tendons the resistance against static and dynamic load as well as the load-transfer to the structure is verified at room temperature. Many design codes allow the use of tendons tested at room temperature between -40°C and +100°C. For temperatures like -164°C special tests are necessary. Common strands usually have a maximum strain of 5 - 7%. According to prEN 10138 the required minimum strain at maximum load is 3.5 %. The maximum strain of a tendon consisting of several strands is usually lower due to the bundling effect and the inclination at the tip of the wedges. Low temperatures may reduce the steel's ductility and may change its failure from ductile to brittle. Thus, the strain at maximum load for strands without anchorage usually is decreasing from approximately 5 - 7 % to a range of 2.5 - 4 % while the maximum load is increasing 8 - 12 % and the yield strength is increasing 5 - 8 %. Similar to the tests at room temperature by the bundling effect usually the maximum strain of a tendon consisting of several strands is lower than that of strands without anchorages. In the European design codes or the ETAG 013 no minimum strain is required.

4. Performance of tests

In Europe tests at cryogenic conditions assume successfully performed tests at room temperature (see Fig. 1). These tests at room temperature have to be performed according to ETAG 013. Within a prestressing system usually three different tendon sizes have to be tested to verify the load transfer to the concrete as well as the resistance against fatigue and static loading. The material properties of all used components have to be examined.

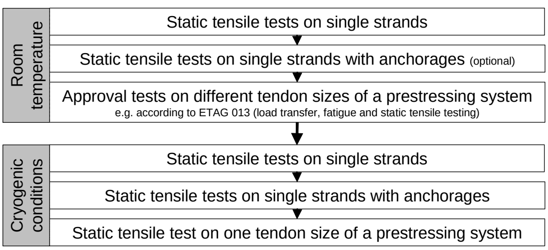

Fig. 1: Flowchart for required tests (at room temperature and at cryogenic conditions)

The strands for tensile testing are used in the as-fabricated condition. The free length of specimen is chosen to approximately 1000 mm. All tests have to be performed on strands of one unit of manufacture.

At Technische Universität München (Technical University Munich, TUM) all tensile tests are performed in a stiff testing rig where the cooling of the strand specimens is possible.

These single tensile tests during the approval process (called: identity tests) are very important because they define the behaviour of that strand unit of manufacture and of those wedges that are used in the multistrand test. For the individual construction projects these single tensile tests shall be repeated with the project specific strands and wedges. If the results are similar it can be concluded that also the multistrand test will be successful and no further bundle testing is necessary.

5. Conclusions

Different recommendations for performing tests to verify the load transfer and the resistance against static load at cryogenic conditions are available. Contrary to the strict requirements of FIP SR 88/2 the requirements in ETAG 013 **Error! Reference source not found.** do not generally guarantee ductile tendon behaviour. Thus, in a progress file of ETAG 013 requirements regarding the minimum strain have to be added.

Anyway, the tests have shown spreading results depending on the used strand. Thus, it is recommended to perform single strand tests with and without anchorage at cryogenic conditions for every specific project. In these tests a minimum strain at maximum load of 2.3 % in tests with anchorage and of 2.5% in tests without anchorage shall be reached.