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FULL-SCALE TESTING OF TWO CORRUGATED STEEL BOX CULVERTS WITH DIFFERENT CROWN STIFFNESS

Esra BAYOĞLU FLENER *, Håkan SUNDQUIST **
*) PhD Student, **) Professor, Department of Civil and Architectural Engineering
Division of Structural Design and Bridges
The Royal Institute of Technology (KTH)
SE-100 44, Stockholm, Sweden

Abstract

We present full-scale tests of one stiffened and one non-stiffened box culvert of 8 m span. The tests comprise measurements during backfilling, static tests by a truck for different cover depths, and ultimate loading. The composite action of the stiffened part was confirmed. The difference between the responses of the two types of structures got smaller with increasing depth of cover. The maximum moment measured at the crown was 22.3 kNm/m. The non-linear curves of maximum displacements and moments demonstrate the positive effect of cover depth. The crown did not respond to live load until the truck was halfway on the bridge. The non-stiffened culvert continued to deflect at 48.8 tons (without increasing the load). The stiffened culvert had not reached its capacity yet by the time all the loads (60.8 tons) were placed on it.

Key words: Box culverts, road bridges, static loads, field tests, monitoring.

1. INTRODUCTION

We present the results of full-scale in-situ tests for the performance of two corrugated steel box culverts of 8 m span in Lidköping, Sweden (Bayoglu Flener, 2006). One of the culverts is stiffened at the crown by means of a crown rib. The tests involved strain and displacement measurements during backfilling, and static measurements under the load of a truck at nine different positions. The culverts were also tested for their ultimate capacities by simulating one axle of a truck. Similarly, the performance of two types of stiffeners was evaluated and the results were compared with a finite-element analysis by McCavour *et al.* (1998). A low profile metal arch culvert with low cover depth was tested on the field and the results were documented in Webb *et al.* (1998). These results were used to assess the performance of 3D finite-element analyses given by Moore *et* *al*. (1999). Tests done on two long-span reinforced deep-corrugated arch culverts were presented in Morrison (2000). The design according to bridge codes and a finite-element analysis results were also provided. More information about such tests and the state of the art can be obtained from (Bayoglu Flener, 2004).

2. THE STRUCTURES

The culvert without the crown rib is called Structure 1, and the one with the rib is called Structure 2. Figure 1 gives the dimensions of the culverts. Each culvert was formed of six rings of corrugated steel plates. Four additional rings of plates (side structures) were constructed on the two ends of the culverts (see Figure 2). The corrugated steel plates were 4 mm thick with a yield strength of 352 MPa. More details about the structures can be found in (Bayoglu Flener, 2006).

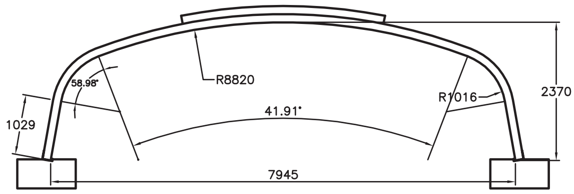


Figure 1. Inner measures of the culvert geometry (in mm)

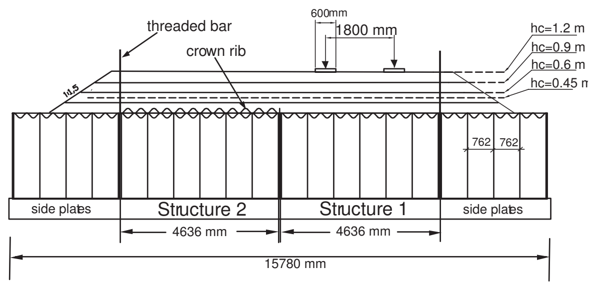


Figure 2. Longitudinal dimensions of the structures and the backfill

3. INSTRUMENTATION AND TEST PROGRAM

A total of 82 strain gauges were installed to measure strains in the bridge longitudinal direction. Three different measurement lines were chosen. The first one was directly under the wheels of one side of the vehicle. The second one was at the centreline between the wheels. The third location was at the crown of the culvert, approximately under the other line of wheels. The numbers and the locations of the main line strain gauges can be seen in Figure 3.

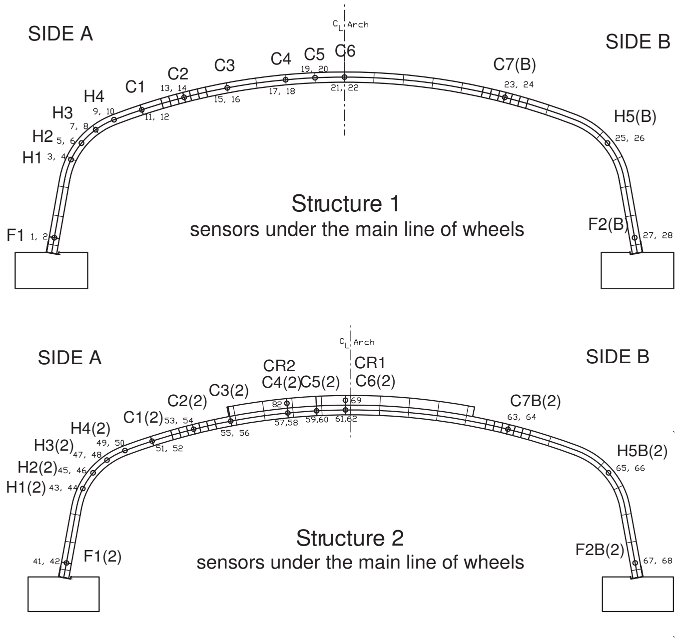


Figure 3. Numbers, locations, and names of the main line of sensors

Six potentiometers were installed to measure the vertical displacements at the crown, the centre of the haunch, and slightly above the footing. Two potentiometers were placed at the haunches for measuring horizontal displacements. Measurements during backfilling were taken both before and after compaction of each layer. (Twelve layers of approximately 300 mm thickness). The measurement layers were 30, 60, 90, 120, 150, 180, 215, 250, 280, 310, 340, and 370 cm from the foundation level. The crown level was 250 cm above the foundation. The static tests were carried out by a fully-loaded three-axle-truck that had a total weight of 34.12 tons. The truck approached the bridge from the side where the culvert was densely instrumented. It was positioned with its rear axle first. The measured weights were 4320 kg and 4340 kg for the left and right wheels of the front axle, 6600 kg and 6750 kg for the left and right wheels of the middle axle, as well as 5880 kg and 5920 kg for the left and right wheels of the rear axle. The static tests were conducted for nine different load positions (namely 4, 3, 2, 1, and 0.5 m before the centreline, exactly on the centreline, as well as 0.5, 0.66, and 1 m after the centreline). Each test was repeated for backfill heights of 120, 90, 60, and 45 cm. A steel beam base was used to perform ultimate loading tests. The contact area of the beam base was equivalent to two tyres of a single axle. It was placed on the crown and at the same lateral position as the truck. Block loads of various sizes were incrementally placed on the loading base.

4. TEST RESULTS

4.1 Measurements during backfilling

According to Figure 4, there was a continuous rise at the crown during the compaction stages where the backfill layer was below the crown level. The maximum crown rise was -12 mm and -6 mm for Structures 1 and 2 respectively at the backfill level of 215 cm from foundation. The maximum vertical displacements at the crown were 19.4 mm and 13.5 mm for Structures 1 and 2 respectively.

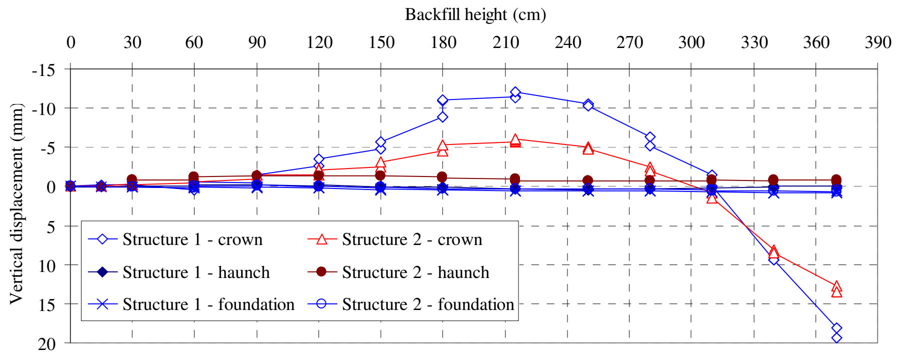


Figure 4. Vertical displacements during backfilling

The maximum compressive strains at the crown centreline (C6) were -562 ms and -288 ms for Structures 1 and 2 respectively. The maximum tensile strains were 268 ms and 115 ms for Structures 1 and 2 respectively. The Structure 2 top sensor measured compression the whole time due to composite action. Structure 1 was much more sensitive to soil loads. The bottom strains reduced to half the value with rib stiffening. The sensor location C3 was almost where the crown rib ends. There was a sudden rise in the strain at point C3, which may mean that there is some stress concentration at the point where the section changes from single to stiffened section.

The maximum compressive force was -243 kN/m measured at C7 after completion of the backfilling. Crown arch thrusts were negative throughout the backfilling process with dramatic increases after the backfill soil reached the crown level (250 cm). However, the axial forces in the haunch were compressive until 280 cm (for H4 and H3) and tensile afterwards. Tensile forces in the haunch area were not normally expected. Moment distributions over the cross-section at the main line of sensors are plotted in Figure 5. The maximum negative moment was measured at C5 as -7 kNm/m for 215 cm backfill height. The maximum positive moment occurred at the same location at the end of the backfilling as 17 kNm/m. The haunch moments were quite small (less than one third) compared to the other parts of the culverts.

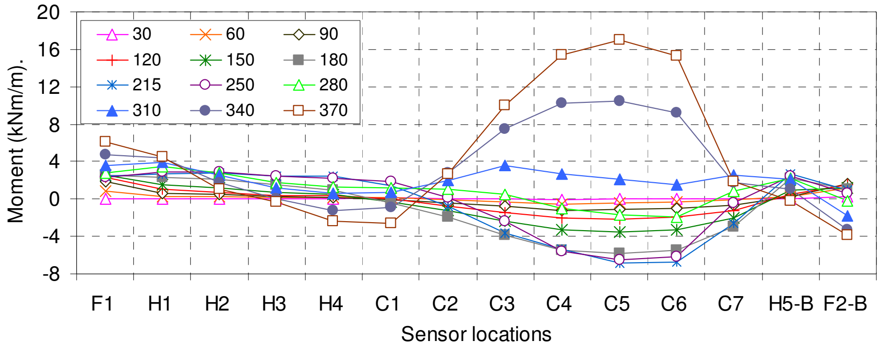


Figure 5. Moment distribution along the main line of sensors for various backfill heights (the backfill height of 250 is the crown level)

4.2 Results of the static tests

Figure 6 displays the effect of increasing the cover depth on the displacements of both structures. The crown displacement of Structure 1 dropped from 12.6 mm to 3 mm as the cover rose from 45 cm to 120 cm. For Structure 2, the change in the maximum displacement was much less. It dropped from 6.6 mm to 3.4 mm (at 90 cm cover) and increased to 3.6 mm (at 120 cm depth of cover). The crown started responding to the live load after 3 m distance to the crown and a more serious response was observed when the trucks first axle got closer than 2 m to the crown centreline. The change in maximum strains with increasing depth of cover within Structure 1 can also be seen in Figure 6.

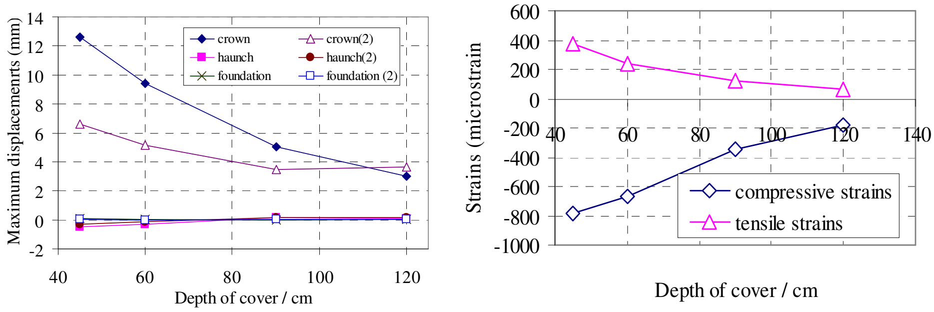


Figure 6. Maximum displacements (Structures 1 & 2) and strains of Structure 1 during truck loading test

The thrusts (compressive) for 45 cm and 60 cm cover depth were -315.9 kN/m (measured at 1 m after the crown) and -283.5 kN/m respectively (measured at 0.5 m after the crown). The maximum thrusts for 90 cm and 120 cm cover depths were -153.9 kN/m and -76.4 kN/m respectively (measured at 0.66 m after crown). The moment for 45 cm cover depth was 22.31 kNm/m, and for

60 cm cover depth it was -18.2 kNm/m (measured at 0.66 m after the crown). The maximum moments for 90 and 120 cm cover depths were 9.7 kNm/m and 5.2 kNm/m respectively (measured at 1 m after crown). The moment distribution graph (see Figure 7) shows that the moments at the haunch areas were very small compared to the crown moments.

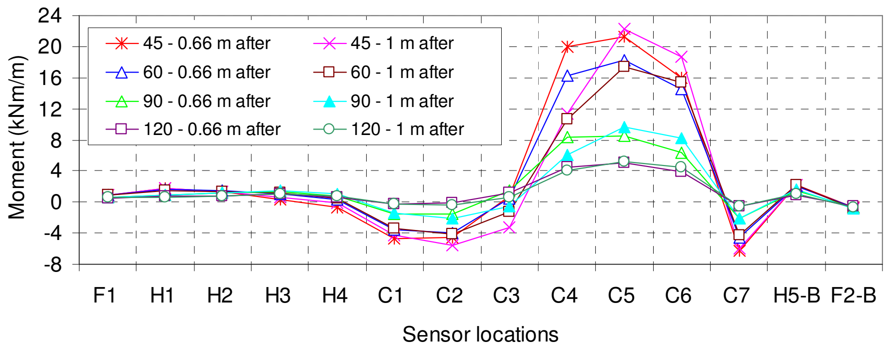


Figure 7. Moment distribution for truck positions 0.66 m and 1 m after the crown (at cover depths of 45, 60, 90, and 120 cm)

4.3 Results of the ultimate loading tests

For Structure 2, the loading continued until all available loads (total of 60.8 tons) were placed on the bridge. No further settlement under constant load was observed. The loading of Structure 1, however, continued until the load level (48.8 tons) where the settlement of the crown continued under the same load. The maximum displacement for Structure 2 was 34 mm. The crown of Structure 1 settled 44 mm when the load reached to 48.8 tons. The displacements continued up to 58.6 mm in the next 40 minutes: see Figure 8.

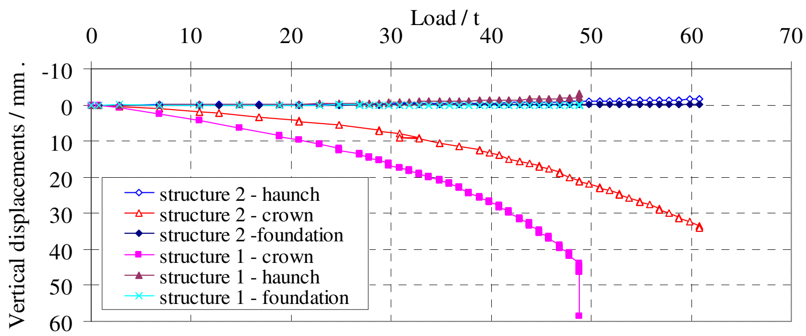
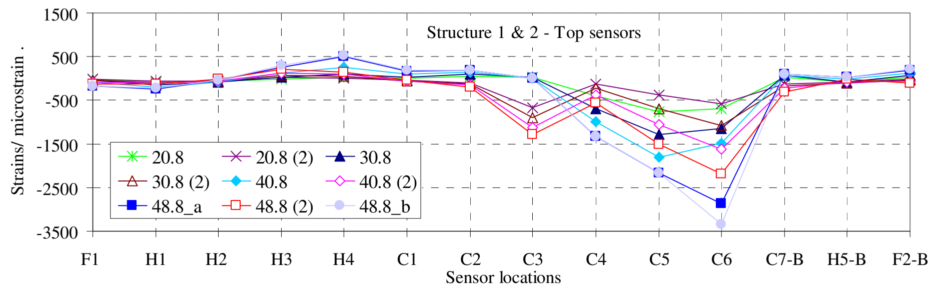


Figure 8. Load-vertical displacement curves for structures 1 & 2

The strain levels reached during the ultimate load test exceeded the elastic range which is approximately 0.16 % (1600 ms). The maximum strains reached for Structure 2 main plates were 1253 ms and -3079 ms. The crown rib top strain was -5044 ms. The tensile strains for Structure 1 reached 3730 ms (starting from 3023) at the ultimate load of 48.8 tons. The compressive strains, on the other hand, increased from -3343 to -4733 ms at the end of the loading. The strain distributions along the main line of sensors for Structures 1 and 2 is seen in Figure 9.



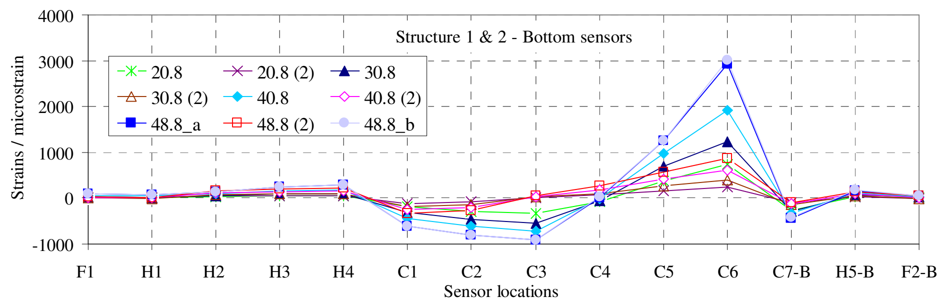


Figure 9. Top and bottom strain distributions of Structures 1 and 2.
(a) Measurement was taken at the beginning. (b) Measurement was taken later

The compressive load can get as big as -758 kN/m. Positive moments as high as 155 kNm/m were calculated at C6. The moment distribution of Structure 1 is given in Figure 10.

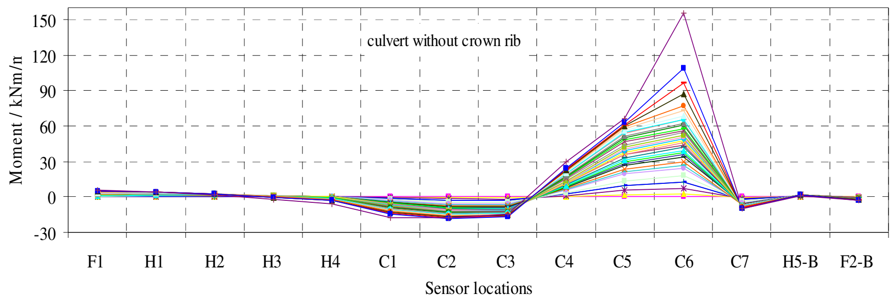


Figure 10. Moment distributions along the main line of sensors in Structure 1 for the ultimate loading test. Each line represents a different load level

5. CONCLUSIONS

A comparison between the deformation mechanisms of the arch culvert in Skivarpsån and the box culvert tells us how much the shape of the structure influences the performance and how much more vulnerable box culverts are to crown loading than arch culverts. The strains in the steel during the ultimate loading tests seem to exceed the elastic strain range. There are several indications of yielding at the location of C6 in Structure 1 whereas Structure 2 does not show yield under the load range that is applied. Structure 1 was unable to take on any more loads without deforming after 48.8 tons, while Structure 2 had not reached its capacity yet by the time all the loads (60.8 tons) were placed on it. The maximum moment calculated at crown location C5 was 66.2 kNm/m. The test results show that the stiffening applied on the culvert Structure 2 works as intended. Displacements during backfilling were much less and the ultimate load carrying capacity seemed to have been increased dramatically. Effects of stiffening were more pronounced when the soil cover is small. The increase in flexural rigidity of the stiffened parts cannot be adequately predicted since full composite action cannot be achieved (at least for higher loads). Factors that might affect the response of the stiffened section are the strength, spacing, and pre-stressing of the bolts, as well as the friction and slippage between the plates. The abrupt change in section stiffness from single plate to the stiffened part might lead to stress concentrations on the parent plate. The cross-corrugation in culverts should be avoided due to their strength-reducing effects. The increase in the depth of cover caused the maximum moment at the crown to decrease. After 90 cm of cover, the effects of live load were less and the positive effect of the soil cover was confirmed.

ACKNOWLEDGEMENTS

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BADANIA W SKALI NATURALNEJ PRZEPUSTÓW Z BLACHY FALISTEJ TYPU BOX O RÓŻNEJ SZTYWNOŚCI W KLUCZU

Streszczenie

Prezentujemy testy w skali naturalnej wykonane dla wzmacnianego żebrami i nie wzmacnianego żebrami przepustu skrzynkowego z blachy falistej o rozpiętości 8 m. Testy obejmują pomiary przeprowadzone podczas zasypywania, testy statyczne wykonane przy użyciu samochodu ciężarowego dla różnych wysokości naziomu i z maksymalną ładownością. Współpraca konstrukcji podstawowej z wzmocnieniami żebrami została potwierdzona. Różnica w zachowaniu się konstrukcji wzmacnianej i nie wzmacnianej pod obciążeniem była coraz mniejsza wraz z zwiększaniem się wysokości naziomu. Maksymalny moment zmierzony w kluczu wyniósł 22.3 kNm/m. Nieliniowe krzywe maksymalnych odkształceń i momentów wykazują pozytywne oddziaływanie wysokości naziomu. Klucz konstrukcji nie reagował na obciążenie dopóki samochód ciężarowy nie znalazł się w połowie mostu. Nie usztywniony przepust ulegał dalszej deformacji przy 48.8 tonach (bez zwiększania ładowności). Usztywniony przepust nawet przy zastosowaniu pełnej ładowności (60.8 ton) nie wykorzystał w pełni swojego zapasu nośności.

Słowa kluczowe: przepusty skrzynkowe, mosty drogowe, obciążenie statyczne, testy terenowe, monitoring.