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FIELD TESTING OF A LONG-SPAN ARCH CORRUGATED--STEEL CULVERT UNDER DYNAMIC AND STATIC LOADS

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Abstract

We present the dynamic and static performance of a long-span corrugated steel culvert railway bridge. The culvert has 7 mm plate thickness, and a 11.12 m span. Two sets of tests were carried out with a locomotive by measuring strains and displacements. The dynamic performance of the bridge under different speeds and braking forces were obtained. The loads do not have a visible effect on the crown before the locomotive passes the footing level. The moments at the crown are not affected as much as the moments at the quarter point. Thrusts are not influenced by the speeds as much as the moments. The values for the braking and dynamic tests are quite close to each other. The dynamic amplification factors based on the maximum vertical displacements of the crown increase significantly after 70 km/h (maximum is 1.24).

Key words: Culverts, railway bridges, dynamic loads, field tests, monitoring,

1. INTRODUCTION

Metal flexible culverts are getting very popular in recent years. The performance of this kind of structures is governed by soil-structure interaction (Bayoglu Flener, 2004a). The design requires several geotechnical aspects such as the bearing capacity of the foundation, long term settlements, interaction between the engineered backfill soil and the structure wall and arching in the soil. Having low flexural stiffness makes metal culverts quite vulnerable during backfilling stages.

This paper describes and presents the results of two similar loading campaigns that are the second and third parts of an extensive field testing work done on a corrugated steel arch culvert made of steel plates of type SuperCor S-37 (Bayoglu Flener, 2004b & 2005). The first tests were performed in October and will be referred to as "October tests". The tests that were done in May will be referred to as "May tests" throughout this paper. The response of the bridge during and soon after construction was presented in Bayoglu Flener *et al.* (2005).

Tests done on two long-span reinforced deep-corrugated structural plate arch culverts were presented in Morrison (2000). The design according to bridge codes and a finite-element analysis were also provided. The performance of two types of stiffeners was evaluated on two box culverts and results were compared with finite-element analysis and presented in McCavour *et al.* (1998). A low profile metal arch culvert with very low cover depth was tested on the field and results were documented in Webb *et al.* (1998). These results were used to assess the performance of three-dimensional finite-element analyses given by Moore *et al.* (1999). Field measurements of a pipe arch long-span steel culvert replacing an old concrete railway bridge were presented by Vaslestad *et al.* (2002) and similarly the results of the tests on another pipe arch culvert slip lining and old brick road bridge were documented in Vaslestad *et al.* (2004). More information about such tests and the state of the art can be obtained from (Bayoglu Flener, 2004a).

2. DESCRIPTION OF THE STRUCTURE

The culvert is a single radius arch depicted in Figure 1. The backfill soil is gravel with 0-45 mm particle size and has a dry density of 2.11 g/cm^3. The degree of compaction (RP) of the soil is 93 %. The section properties of steel plates and more details about the structure can be found in Bayoglu Flener (2004b). The tests were carried out by an RC4 locomotive engine that has four axles and has a total static service weight of 78 tons.

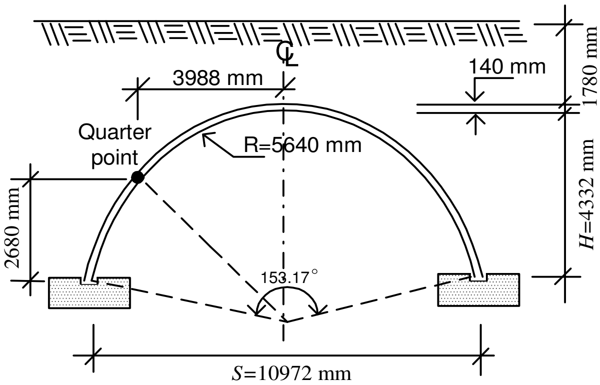

Figure 1. Sectional dimensions and geometry of the culvert structure (not to scale)

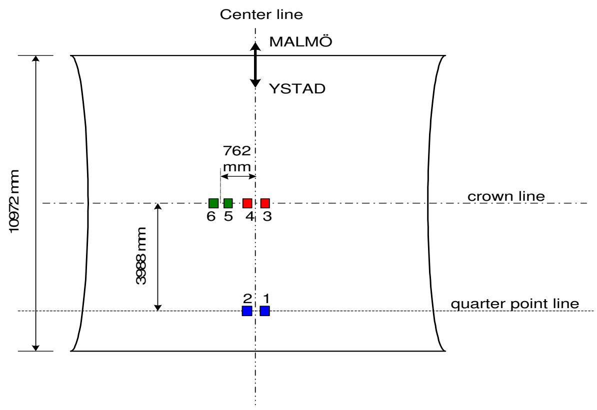

Figure 2. Culvert from the top with locations of strain gauges and travel directions

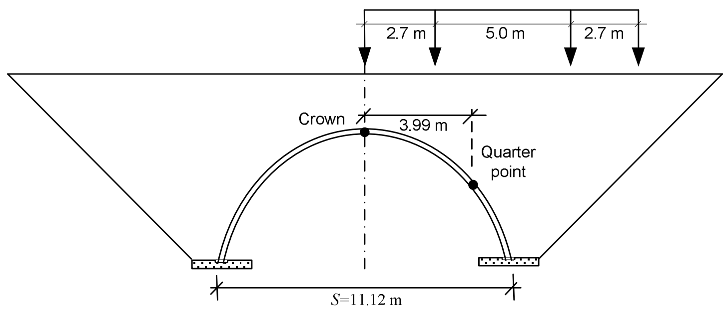

Figure 3. Demonstration of the static test axle loads when the first axle of the locomotive is above the crown of the culvert

3. INSTRUMENTATION AND LOADING PROGRAM

All the strain gauges measured strains in the bridge longitudinal direction. They were located at the crown along the centreline (sensors 3 & 4), 762 mm eccentric from the centreline (sensors 5 & 6), and at the "quarter point" along the centreline of the bridge (sensors 1 & 2) (see Figure 2). The vertical displacement of the crown was monitored by means of a variable differential transformer (LVDT). Vehicle speeds were measured using laser beam speed-readers.

The static load tests were conducted for a total of 11 different locomotive positions. Positions of the first axle were 11 m (only in October tests), 8.25 m, 5.5 m, 2.75 m before the crown, on the crown, 1.5 m (only in May tests), 2.75 m 5.5 m, 8.25 m (only in May tests), 11 m (only in May tests) and 16 m (only in May tests) after the crown. See Figure 3 for the of the static test and axle loads.

In dynamic tests, the locomotive passed with constant speeds of 10, 30, 50, 70, 90, and 125 km/h. The tests were repeated for the two travel directions.

Braking tests were performed with 4 different travel speeds (30, 50, 70, and 90 km/h). The speeds before braking were chosen such that the desired speeds can be reached when the locomotive arrives at the bridge in the second test.

4. TEST RESULTS AND CALCULATIONS

The sign convention in this paper is that (+) is tension and positive moments show compression at the top. Data filtering was necessary to achieve values free from noise. In the October tests, the cut off frequency for filtering the data was chosen as 60 Hz. In the May tests, for some of the dynamic test results (tests with 10, 30, and 50 km/h), a 30 Hz low-pass filter was found to be the most suitable. The dynamic amplification factor on vertical displacement of the crown (a_{disp}) is calculated according to Equation 4.1. Dynamic amplification factors with respect to moments and thrusts (a_{moment} and a_{thrust}) are calculated in the same manner.

$$a_{disp}(i) = \frac{\delta_{dyn} i}{\delta_{sta}} \tag{4.1}$$

where $a_{\text{disp}}(i)$ = dynamic amplification factor for speed i, while d_{sta} = maximum static displacement, and $d_{\text{dyn}}\, i$ = dynamic displacement for speed i.

4.1 Results of the static tests

Static test results for different positions of the load are shown in Figure 4. The difference in measurements in the two different sets of tests can also be seen. The October crown thrusts seem to be higher than in May, especially when the first axle of the locomotive is 2.75 m beyond the centreline. The quarter point thrusts peak when the first axle is on the centreline of the bridge. The quarter point moments are very close in both tests. The crown centreline moments are very close while the October crown eccentric moments are quite lower than the May ones.

4.2 Results of the dynamic and braking tests

The maximum vertical displacement of the crown with different speeds is demonstrated in Figure 5. It is possible to compare the braking test results with the dynamic tests results as well as the two different measurement campaigns. The difference between braking and dynamic test is more pronounced in the May tests.

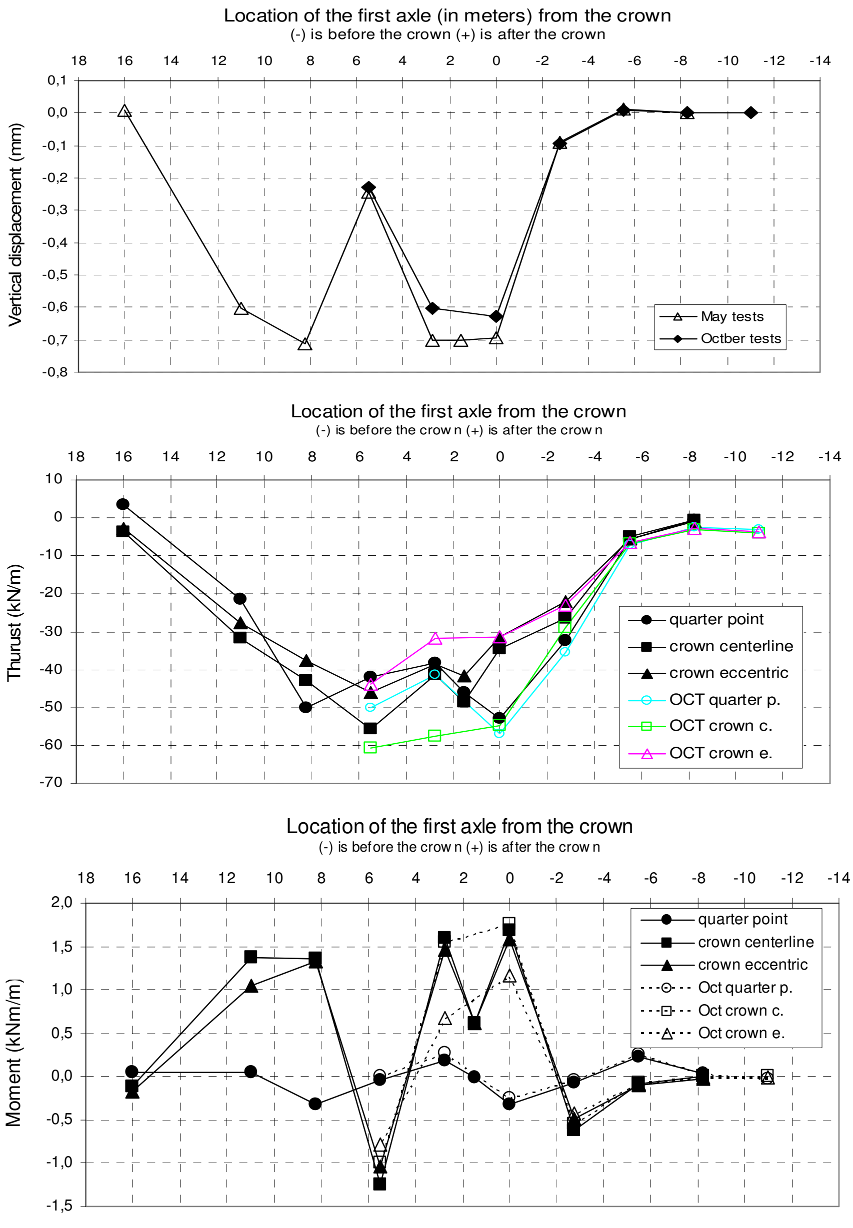

Figure 4. Maximum downwards vertical displacements of the crown, thrusts, and moments during static tests for different positions of the first axle of the locomotive

In the May tests, the percentage increase in displacements with unit increase in speeds was calculated as 0.17 for the dynamic tests in the Ystad-Malmö direction, and as 0.20 for the dynamic tests in the Malmö-Ystad direction, and as 0.16 for the braking tests. In the October tests, the percentage increase in displacements with unit increase in speeds was calculated as 0.36 for the dynamic tests in the Ystad-Malmö direction, as 0.26 for the dynamic tests in the Malmö-Ystad direction, and as 0.16 for the braking tests.

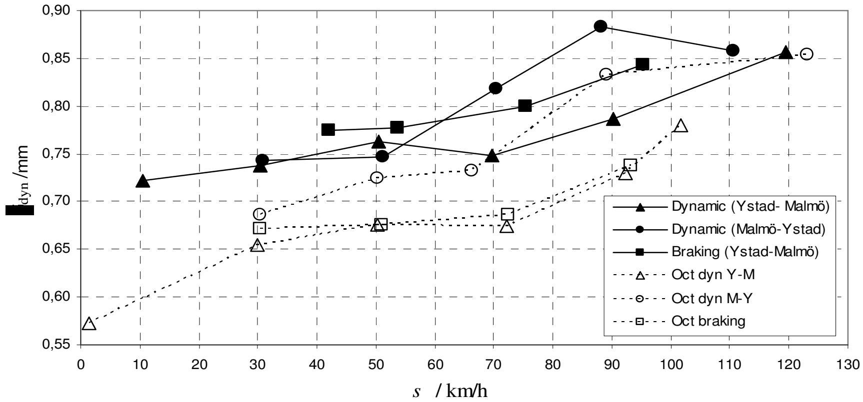

Figure 5. Maximum downwards vertical displacements of the crown during dynamic and braking tests

In the May tests, the thrusts measured (when the first axle of the locomotive is on the crown) at the crown centreline at the braking and dynamic tests in the Ystad-Malmö direction are very close The values vary between -35 kN/m and -45 kN/m. The thrusts from the dynamic test in the Malmö-Ystad direction have slightly lower values. The October test results have the same tendency but higher values that change between approximately -55 kN/m and -62 kN/m. The increase in thrusts with increasing speeds is much more pronounced in some of the tests but they do not show a steady and consistent increase.

Thrusts for 50 km/h speed at the crown centreline and eccentric give the same response to the position of the locomotive in the May tests, whereas in the October tests eccentric thrusts are less compared to the ones measured at the centreline. The maximum thrusts (approximately -60 kN/m) are observed when the middle of the locomotive is on the crown. The quarter point has the opposite response with a minimal compression of -37 kN/m when the middle of the locomotive is on the crown.

In the May tests, (upon calculations when the first axle of the locomotive is on the crown) a constant increase in moments (up to 2.05 kNm/m) at the crown can only be observed for the tests done in the Malmö-Ystad direction. There is a difference between the moments measured at the dynamic and braking tests for the same driving direction of the locomotive. The braking test results are higher.

The values of the quarter point moments with respect to the position of the locomotive range approximately between -0.4 kNm/m and 0.25 kNm/m. Positive moments occur when the middle of the locomotive is at the crown of the culvert. Positive moments (up to 2 kNm/m) at the crown level occur as the axles of the locomotive are passing the crown. Negative moments up to -1.4 kNm/m are measured when the middle of the locomotive is at the crown level.

In the October tests, the average increase in moments with unit increase in speeds is 0.004 kNm/m. The maximum % increase with unit increase in speed was calculated as 1.16 % and the average of all tests is 0.43 %. In general, the speed effect on moments seems to be more pronounced at the quarter point than at the crown. In the May tests, some amount of change in moments with increasing speeds was observed. The average increase in moments with unit increase in speeds is 0.003 kNm/m. The maximum % increase with unit increase in speed was calculated as 0.62 % and the average of all tests is 0.07.

4.3 Dynamic amplification factors

Dynamic amplification factors were calculated according to Equation 4.1. Figure 6 shows the factors calculated with respect to the maximum vertical displacements of the crown. A comparison of the thrusts and moments of the static tests with the dynamic tests for the positions of the locomotive where the first axle, the second axle, and the middle of the locomotive are on the crown were done. The resulting average dynamic amplification factors for different speeds are shown in Figure 7.

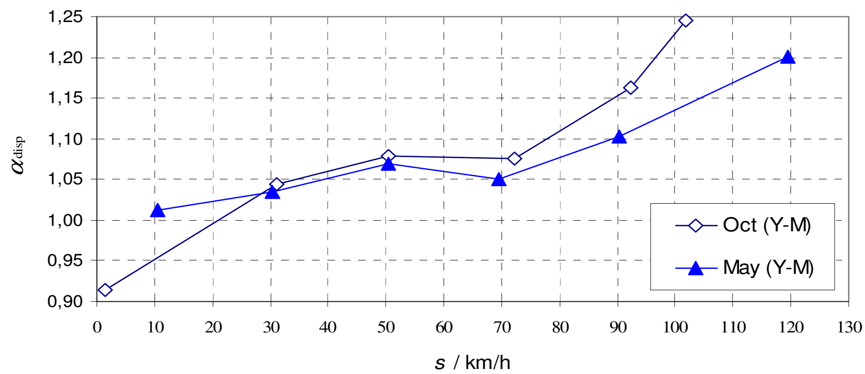

Figure 6. Dynamic amplification factors w.r.t. vertical displacements of the crown

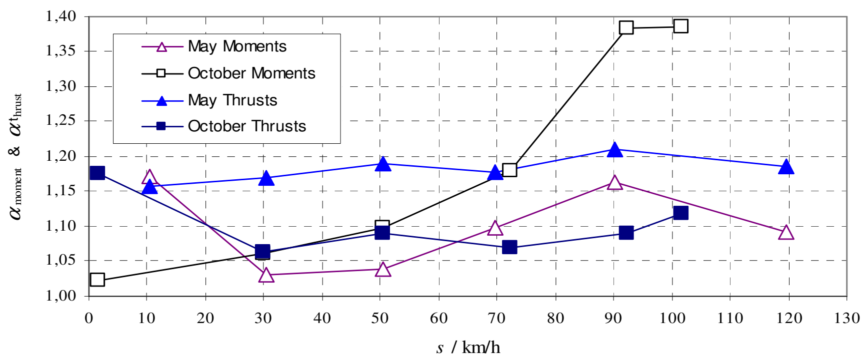

Figure 7. Average dynamic amplification factors w.r.t. moments and thrusts

5. CONCLUSIONS

Displacements in the May dynamic tests are slightly larger than the October ones. A negligible load is transferred to the structure when the load is beyond the footing level. The moments at the crown are not affected as much as the moments at the quarter point with increasing vehicle speed. Thrusts are not influenced by the speeds as much as the moments. Braking on the bridge does not seem to have additional force on the bridge. Dynamic amplification factors based on the maximum vertical displacements of the crown increase up to 1.24 for 100 km/h. The increase in the factors is more significant after 70 km/h.

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BADANIA POLOWE DUŻEJ ROZPIĘTOŚCI ŁUKU ZE STALOWEJ BLACHY FALISTEJ POD OBCIĄŻENIEM STATYCZNYM I DYNAMICZNYM

Streszczenie

W pracy prezentujemy zachowanie się mostu kolejowego wykonanego ze stalowej blachy falistej pod wpływem obciążeń statycznych i dynamicznych. Grubość blachy przepustu stalowego wynosi 7mm, jego rozpiętość – 11,12 m. Przy użyciu lokomotywy przeprowadzono dwie grupy testów mierzących odkształcania i przemieszczenia. Obserwowano zachowanie się konstrukcji mostu przy obciążeniach dynamicznych przy różnych prędkościach i pod wpływem sił niszczących. Nie zaobserwowano istotnego wpływu obciążenia na wartości mierzone w klucz, zanim lokomotywa znajdzie się na wysokości podparcia. Wpływ obciążenia na moment w kluczu nie jest tak duży jak na momenty ¼ rozpiętości. Prędkość przejazdu nie ma tak istotnego wpływu na wartość sił normalnych jak na momenty. Pomierzone wartości z testów niszczących i dynamiki są do siebie zbliżone. Współczynniki dynamiczne bazujące na maksymalnym pionowym odkształceniu klucza rosną znacząco po przekroczeniu 70 km/h (maksymalny wynosi 1.24).

Słowa kluczowe: przepusty, wiadukty, obciążenie dynamiczne, testy terenowe, kontrola