MRTS90

Modular Bridge Expansion Joints

APPENDIX B

Outline of Test Procedure for Experimental Modal Analysis

Table of Contents

B1 Test Description

The measurement and definition of the natural frequencies and mode shapes of a structure is referred to as Modal Analysis. The general test etiquette and methodology for such analysis is described below (refer also to Ewins D J *Modal Testing: Theory, Practice & Application*. The main aims of the test described in this appendix are to determine the mode shapes, natural frequencies, modal damping and Dynamic Amplification Factor (DAF) for the MBEJ system plus the dynamic compression stiffness and damping factors of the bearings and pre-compression springs, under a simulated load case. Data obtained from an experimental modal analysis shall be used to calibrate any dynamic finite element (FE) method model developed to assist in the fatigue design of the MBEJ. This is seen as being a two-part process. Firstly, the dynamic FE model shall accurately represent the mode shapes and modal frequencies from the experimental study and, secondly, the FE model shall be able to duplicate measured static and dynamic strain gauge results. Matching the dynamic strains may require some adjustment to the applied wheel load. This “adjustment” is in effect an additional “calibration factor”.

B2 Measurement of Frequency Response Functions

B2.1 MBEJ System

These measurements involve the simultaneous measurement of input force and vibration response. In these tests, force, over the frequency range of interest, shall be imparted to the structure using a suitable shaker or force hammer. The shaker shall be connected to the structure via a force transducer. The vibration response shall then be measured at selected locations using at least one accelerometer attached to the structure with a magnetic base or other suitable attachment method. In the case of in-situ modal testing, the measurements shall only be conducted in the absence of traffic crossing the expansion joint. Where measurements are undertaken on an expansion joint at the place of manufacture, great care shall be exercised to ensure that the boundary conditions closely match those of an installed expansion joint.

A “dynamically similar” modular joint is one in which the design (single support bar or multiple support bar, etc.), bearings, pre-compression springs, centring mechanism and structural steel components are identical to the modular joint proposed in conformance with this Standard. However, the spacing of support bars and the number of centre beams does not need to be identical.

The input force and vibration response at each location shall be simultaneously measured using a minimum two-channel FFT analyser. Frequency Response Functions (FRF’s) shall then be stored for each measurement.

A minimum of 100 measurement locations are considered necessary to adequately define relevant MBEJ system mode shapes (unless otherwise justified). The extent of measurements shall include at least two bays of the expansion joint (In this context, a “bay” is defined as the space between two consecutive support boxes).

Measurements shall be in three component directions (i.e. vertical, transverse and longitudinal) at each location. Simultaneous measurement at all (minimum 100) locations is not necessary and simultaneous two channel measurements at a time are acceptable (i.e. Channel A – Reference Accelerometer, Channel B – Roving Accelerometer or Force Hammer).

B2.2 Bearings & Pre-compression Springs

B2.2.1 General

The bearings and pre-compression springs to be tested shall be placed in a suitable test apparatus as described in Clauses B2.2.2, B2.2.3 and B2.2.4.

B2.2.2 Test Procedure

The under side of the test bearings shall be supported on a rigid flat surface with a vertical stiffness of at least 10 times that of the test bearings.

The test bearings shall be arranged to support a test mass in a stable manner. For a typical MBEJ, the test mass shall equal a nominal 600 kg per test bearing. (i.e. a 2400 kg test mass supported evenly by four test bearings would be suitable).

B2.2.3 Alternative Test Procedure No.1

As an alternative to the test described in Clause B2.2.2, a two mass arrangement may be used. A base mass shall be supported on soft springs upon which the primary mass is mounted via test bearings. The primary suspension mode shall be less than 6 Hz. The dynamic stiffness and damping properties are extracted from the second vertical bounce mode, i.e. out of phase motion of the primary and base mass. Details of the dynamic stiffness property calculations shall be fully documented in the test report.

B2.2.4 Alternative Test Procedure No.2

The following test procedure is also available as an alternative –

a) a suitable rigid mass, i.e. solid steel block (nominal mass to be supported by each bearing assembly, eg 100 kg) shall be supported in a suitable test frame;

b) the test frame shall be arranged so as to mount the test mass on top of the test linear bearing and below the test top spring – a hydraulic jack or suitable calibrated preload device shall be mounted in series;

c) the nominal design pre-load shall be applied prior to dynamic testing;

d) modal testing of the test mass shall be carried out in sufficient detail to identify the fundamental bounce mode of the test mass suspended between the test bearings;

e) the dynamic stiffness and damping for test bearing set shall be extracted; and

f) the input force and vibration response at each location shall be simultaneously measured using a minimum two-channel FFT analyser and Frequency Response Functions (FRF's) shall then be stored for each measurement

The test frame shall be a minimum 10 times stiffer than the combined stiffness of the test bearing set, (i.e. the test frame and preload device shall not significantly contribute to the controlling stiffness of the target bounce mode).

A minimum of 4 measurement locations are considered necessary to adequately define relevant mode shapes (unless otherwise justified). Measurements shall be in three component directions (i.e. vertical, transverse and longitudinal) at each location.

An example of a typical measurement instrumentation set-up for all dynamic tests is shown as Figure B1.

B3 Extraction of Modal Parameters

This shall be achieved by processing the FRF measurements with suitable modal analysis software such as SMS STARStruct® or equivalent.

The stages in this process shall be –

a) the first 5 vertical modes shall be identified;

b) FRF measurements shall be curve fitted and modal parameters shall be produced (frequency and damping tables, mode shape tables);

c) the mode shapes shall be animated and displayed;

d) the mode shapes shall be animated and displayed again within the modal software by entering the three dimensional coordinates of all measurement points to produce a line drawing of the structure; and

e) the resulting residues (from the shape tables above) shall be superimposed on the line drawing and animated for viewing.

B4 Analysis and Report

The above resulting Natural Mode Data shall be used in order to determine –

a) an understanding of the dynamic response of the structure under actual vehicle pass-by excitation; and

b) an understanding of the dynamic amplification factors, (DAF) which may contribute to the structural failures (eg. weld cracking at centre beam to support bar connection).

In the determination of the DAF, consideration shall be given to –

- the mode shapes involved;
- the modal damping for critical modes;
- the wheel pass frequency range;
- the vehicle speed and axle spacing for multi-axle vehicles;
- the structural continuity of the MBEJ system;
- the damped natural frequency of the fundamental bounce mode of the test mass for the bearings and the pre-compression springs;
- the damping factors associated with the bearing and pre-compression spring modes; and
- the dynamic compression stiffness for the bearings, and the pre-compression springs.

The test report shall detail all test procedures, conclusions and recommendations, including detailed steps used in the determination of the modal parameters.

In the case of in-situ testing, the determination of the DAF range may be assisted by component vibration measurements under traffic excitation, i.e. traffic response vibration tests.

The test report shall detail all test procedures, conclusions and recommendations, including detailed steps used in the determination of the DAF range. The test report shall also provide full size A4 plots (landscape) of representative FRF's for every natural mode identified (magnitude and phase).

Where the DAF assessment produces a probable range of values, the design DAF shall be calculated as follows –

$$\chi_{\mathrm{mod}} = (3\chi_{UB} + \chi_{LB})/4 \qquad (B.1)$$

where χ_{UB} and χ_{LB} are the upper and lower bound values of the DAF.

Animation and display of mode shapes shall be achieved again within the modal software by entering the three dimensional coordinates of all measurement points to produce a line drawing of the structure.

The resulting residues (from the shape tables above) shall then be superimposed on the line drawing and animated for viewing. The main purpose of mode shape animation in these tests is to identify whole body and flexural modes of the MBEJ system and to positively identify the fundamental bounce mode of the bearing test mass.

Figure B1 – Impact and Exciter Testing