In-Service Monitoring of a Cantilever Sign Gantry
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SYNOPSIS
VicRoads discovered fatigue related anchor rod defects cantilever sign gantries in Victoria.. Gantry failures were discovered in the USA in the mid 1990's and extensive research was carried out by the NCH in the USA and this has culminated in a design specification produced by AASHTO. VicRoads have advised that this standard (or equivalent) be used for all future cantilever gantry designs. There is an unresolved issue concerning the susceptibility of cantilever sign gantries (of box section construction) to vortex shedding actions. The AASHTO specification indicates that vortex shedding is “almost never” a significant action observed in failures in cantilever sign gantries in the USA, and appears to ignore it in general design considerations.

As Leighton’s design consultant, GHD recommended that the opportunity to monitor the re-installed original gantry at Broderick Road for a limited period be taken to get a better understanding of the behavior of the gantry in the field, and compare it with the AASHTO design actions. This paper presents the data captured, and GHD’s analysis, conclusions and recommendations.

Introduction - Cantilever Gantries in Victoria
Prior to 2007, cantilever gantries had been used in Victoria on many highway projects without any reported problems. It is worth noting that the original VicRoads cantilever sign gantry standard detail indicated a maximum cantilever out-stand of 8m. With the development of project requirements over the last decade, the required cantilever gantry sign out-stand has increased to around 13m, with a box section structure specified by project landscape architects (and preferred by contractors for their simplicity in fabrication). During 2007, structural defects in gantry baseplate anchor rods were discovered by VicRoads. VicRoads issued an interim Bridges Technical Note 13 (BTN13) in July 2007 [1] to alert designers to the issue, and seek their comment.

Broderick Road Cantilever Sign Gantry
The baseplate anchorage for one gantry (carrying the Broderick Road sign), located near Geelong, was found to have a completely fractured anchor rod. The Broderick Road Gantry was designed by GHD in 1999 and constructed by Leighton Contractors in 2000. The gantry was designed to Austroads 1992 [2]. The current design standard for cantilever sign gantries is AS5100: 2004 [3], which is essentially the same as Austroads 92 for cantilever sign gantries.

The details of the Broderick Road cantilever sign gantry are summarised in Table 1, and the general arrangement is shown in Fig 1.

Table 1: Broderick Road Sign Cantilever Sign Gantry Data
<table>
<thead>
<tr>
<th>Description</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height of column</td>
<td>8480mm</td>
</tr>
<tr>
<td>Length of cantilever out-stand</td>
<td>12300mm</td>
</tr>
<tr>
<td>Dimensions of sign</td>
<td>3600mm (b) x 2400mm (h)</td>
</tr>
<tr>
<td>Box section dimensions</td>
<td>600mm x 600mm (12 thick)</td>
</tr>
<tr>
<td>Anchor rods</td>
<td>6 No. 36mm dia. (grade 8.8)</td>
</tr>
<tr>
<td>Natural frequency (vertical)</td>
<td>1.7 Hz</td>
</tr>
<tr>
<td>Natural frequency (lateral)</td>
<td>1.5 Hz</td>
</tr>
<tr>
<td>Orientation of outstand</td>
<td>100 degrees (0 degrees = north)</td>
</tr>
</tbody>
</table>

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**Investigation of the Failed Baseplate Anchorage**

GHD inspected the failed baseplate anchorage for Leighton Contractors, and reviewed the original design. The baseplate assembly (similar to that used for the Broderick Road sign gantry) is shown in Fig 2.
The failure surface of the anchorage rod was examined by Metlabs and determined to have ‘beach’ marks which indicated that the mode of failure is fatigue.

The design standard for the original Broderick Road cantilever gantry design (1999) contained no clear and specific requirements for designing cantilever gantry signs for fatigue actions (and neither does AS 5100). The VicRoads Bridges Technical Note [1] directs designers to use the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (2001) [4]. This AASHTO design specification is based on extensive research into the failures of sign gantries in the USA.

**Brief Summary of Research and Design Specifications in the USA**

AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals (1994) Was generally accepted to be vague and insufficient with respect to the design of support structures for vibration and fatigue. Also, the commentary to the 1994 Specifications did not contain adequate guidance for their application. An increasing number of reported fatigue failures in cantilever sign gantries prompted the National Cooperative Highway Research Program (NCHRP) research, which is summarized in the table below:
Table 2: Summary of Research in the USA

<table>
<thead>
<tr>
<th>NCHRP Project</th>
<th>NCHRP Report</th>
<th>AASHTO Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>17-10(2) ENHANCEMENTS to the AASHTO Specifications for the design of structural supports for highway signs, luminaires, and traffic signals. Completed in June 2002. To be published as a NCHRP Report.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The design of cantilever sign gantries has been the focus of research in the USA, following a number of failures. The experience gained in the USA provides substantial documentation to assist in better understanding the behavior and failure of these structures.

The AASHTO design code appears to be the most comprehensive observation of gantry in service performance available and is therefore a sound basis for checking the original designs, and the proposed rehabilitated designs for performance under fatigue related actions.

For the rehabilitation of the cantilever gantries on the Geelong Road project, The AASHTO Standard Specification was the basis for the design checks for fatigue.

AASHTO considers four main actions which could give rise to fatigue effects in the sign support structures: (1) Galloping; (2) Natural Wind Gust; (3) Truck induced; and (4) Vortex Shedding.

Research carried out by the NCHRP for AASHTO in the USA suggests that vortex shedding was not observed to be a factor in failures, but the recommendations stop short of a definitive statement concerning vortex shedding. In the AASHTO Specification, clause 11.7.2, the advice is that cantilever sign gantries are almost never susceptible to vortex shedding. The problem is that the clause raises a possibility that vortex shedding might under some circumstances be significant. In the light of this element of uncertainty, and the consequences of a fatigue failure in the anchorage rods of a structural form with no alternative load paths, GHD recommended some limited monitoring of the unmodified Broderick Road cantilever gantry.

The rehabilitated designs were capable of handling effects (1) to (3), however, the most reliable and economical method of dealing with possible vortex shedding was thought to be impact dampers.

Leighton Contractors also agreed with GHD that in view of the lack of design data on the wind induced vibration response of long out-stand cantilever gantries, that the original Broderick Road gantry should be the subject of limited in-service vibration monitoring, prior to confirmation of the rehabilitation work to be carried out on the remaining gantries for the project. This paper presents a summary of the monitoring work carried out, an analysis of the data captured, and some provisional conclusions.

**Monitoring of the In Service Performance of the Broderick Road Sign Gantry**

Following the reconstruction of the pilecap and anchor rods, the unmodified Broderick Road sign gantry was instrumented and re erected. Marshall Day Acoustics were appointed to undertake the monitoring of the gantry.

Two sets of instrumentation were installed:

Primary: vertical and lateral direction accelerometers located at the cantilever tip.
Secondary: vertical, lateral and longitudinal accelerometers located 2.3m from the column

Wind speed was measured from a detector installed 10m from the sign, at a height of 3m above the ground.

The gantry was monitored using the primary and secondary instrumentation between 20th November and 5th December 2008.

**Fig 3:** Instrumented Cantilever Arm being Lifted onto the column

**Observations**

A significant vibration event was recorded on the 30th November 2008 (see Fig 4).

**Fig 4:** Record of Significant Vibration Event - 30th November 2008

The vibration was significant as the amplitude of vibration was high for a relatively low wind speed. The principal observations from the monitoring data were:
• Peak vibrations (giving maximum cantilever tip deflections of 21mm lateral and 15mm vertical) were observed when the wind direction was approximately parallel to the face of the sign.

• Wind speed causing the vibrations was low (29km/h)

• Max vertical and longitudinal vibrations do not occur at the same time.

• A larger event (vibrations 50% larger) was recorded during setting up of the monitoring system (25th November 2008).

Discussion

Significant vibration of the tip of the cantilever appears to occur when wind is parallel to the sign face. Wind direction approximately parallel to the sign face appears to occur for significant periods of time (for example approximately 32% of the Avalon records for 2008). When wind direction is parallel to the sign face, the structure which presents to the wind is a simple vertical column (as the cantilever and sign are hidden behind the column). The calculated frequency of vortices which may be shed from the vertical column is 1.6Hz, which is similar to the measured frequency of the cantilever tip, vibrating in the lateral (horizontal) direction.

The upper limit of vibration amplitude could not be determined from the monitoring results. It is a particular concern to designers that vibrations caused in this way could lead to significant accumulating fatigue damage in any long out-stand cantilever sign gantry with a sign attached at the tip of the cantilever.

The Broderick Road gantry fatigue failure took 7 years. The calculated fatigue life for vortex shedding induced loading (according to AASHTO) is only weeks. It would therefore seem reasonable that the observed vibrations are something new, and needs to be investigated further.

Provisional Conclusions

It is difficult to draw firm conclusions from a very limited set of data, and further work is required to confirm the finding of this work.

There appears to be a link between vortex shedding from the vertical column and lateral vibration of the cantilever tip when the wind direction is parallel to the sign face. Vortex shedding appears to be significant on the Broderick Road cantilever sign gantry.

It would appear prudent to consider vortex shedding in the detailing of cantilever sign gantries. As the phenomenon appears to be very specific to wind direction, it is possible to eliminate the problem by attaching strakes to the sides of the column (similar to the way in which the top 20% of tall chimneys are treated), to spoil the vortex street, and thereby remove the source of lateral excitation of the cantilever tip.

Suggested Way Forward

Long out-stand cantilever sign gantries (with arms greater than 9m) should be considered for the retrofitting of strakes on the column face on the sides parallel with the face of the sign.
Wind tunnel tests may provide assistance in identifying the length of out-stand and area of signage which are at greatest risk of fatigue damage due to vortex shedding. The development of effective strakes may also be tested in the wind tunnel.

Further long term monitoring of an ‘at-risk’ cantilever gantry which has been retrofitted with strakes would validate the proposed retrofit strake solution.

Conservative design for the baseplate connection is essential, as there is no redundancy in this type of structure, and the consequences of failure are serious. Agreed standard designs are required.

**Recommendations**

The maintenance burden demanded for this type of structure and baseplate is significant (regular NDT testing is the only practical option). Fatigue failures in these anchor rods are not easily detected by NDT testing, therefore the residual risk of future failures in this type of structure baseplate anchorage designed prior to 2007 is high. Therefore, as noted in the AASHTO Specification, monitoring of cantilever sign gantries for fatigue damage is not an effective means of managing the risk of failure. A different approach is required.

Development of a national approach to the design and detailing of new cantilever sign gantries, which includes:

- Prescriptive requirements for the conservative design of the baseplate connection.

- An anchor rod detail which is designed to rely on the anchor rods to resist all forces (which implies that a system that uses levelling nuts and no grout is required).

Development of a national approach to the safe management of existing cantilever sign gantries, which includes:

- Wind tunnel tests to confirm the findings of the Broderick Road monitoring, and the development of a practical and effective retrofitted strake detail.

- Definitive design advice on the application of vortex shedding to cantilever sign structures in Australia

**References:**


**Additional Related References of Interest to Designers:**

Guidelines for the Installation, Inspection, Maintenance and Repair of Structural Supports for Highway Signs, Luminaries, and Traffic Signals
http://www.fhwa.dot.gov/bridge/signinspection.cfm


Fatigue Life Evaluation of Changeable Message Sign Structures – Volume 1 – As Built Specimens; Amir S Gilani, Juan V Chavez, Andrew S Whittaker; Earthquake Engineering Research Centre, University of California at Berkeley, Report No. UCB/EERC-97/10, November 1997


Specification for Structural Joints Using ASTM A325 or A490 Bolts, Research Council on Structural Connections Committee A1, June 30, 2004