Michigan Department of Transportation - M•DOT

# Mates

**Issue No. 62** **April 1992**

## CANTILEVER SIGN SUPPORTS

Most Michigan motorists are so accustomed to passing under a cantilever sign structure that they drive beneath them without notice. These are the structures that consist of a vertical steel column with horizontal arms attached, cantilevering the sign panels over the roadway. In 1990, the collapse of two cantilever sign supports threatened to erode public confidence. This article is intended to explain the problems that were discovered with these cantilevered sign structures and the action that was taken to make them safe. It will concentrate on the larger sized cantilever sign supports.

### Vortex Shedding and Loosened Nuts

What is vortex shedding? A simple example of this can be seen by taking an ordinary plastic soda straw, holding it at one end, and placing it in front of a fan. By adjusting the distance of the straw from the fan, and the speed of the fan, you should be able to see the straw vibrate in a back and forth motion. As the fan blows air across the straw, whirlwinds (vortices) are created behind the straw (Fig. 1). Similar vortices can be observed as whirlpools in a stream when water flows past fixed objects. The vortices occur in a particular pattern that creates a load on the straw perpendicular to the flow of air. These vortices occur at a frequency behind the straw that can, at times, match the natural frequency of the straw. When this happens, resonance (i.e., excitation of a natural frequency of vibration) with the straw occurs, which creates a large number of vibrations at an increased amplitude.

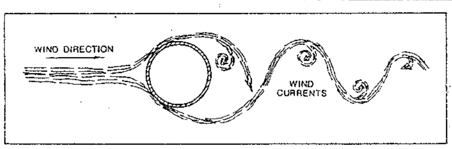


Figure 1.

What is natural frequency? As an example, if one takes a common household knife and holds the end of the blade tightly against the kitchen countertop, then takes the other hand and plucks the free end of the knife, the end that is free will vibrate up and down at a certain frequency. If you could count the cycles in a second that the knife vibrates, that would be its natural frequency. Now compare this with a cantilever sign support. The sign support structure itself, including the sign panel, has a natural frequency and each individual component has a natural frequency. When the wind blows by this support it is likely that vortices are created behind the structure, which in turn create a load on the structure perpendicular to the direction of wind flow. This load, created by the vacuum formed when vortices shed from the structure, can match the sign support's natural frequency. When this happens resonance has occurred, and the anchor bolts holding the sign structure to its base experience a high number of cyclic stresses (stress range), which can cause fatigue cracking in the bolts. This fatigue cracking, once initiated, can progress when resonance occurs on subsequent wind loadings, leading to complete fracture of the anchor bolt.

Some of the nuts on the high strength bolts that connect the horizontal arms to the vertical upright and on the anchor bolts that connect the base plate of the vertical upright to the concrete foundation (Fig. 2) can become loosened. Causes of these loose nuts could be due to inappropriate erection procedures, inaccurate tightening methods, or vibration from vortex shedding. Even though the causes of loose nuts are not known for certain, the effects are dramatic.

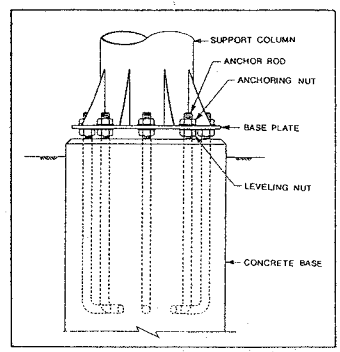


Figure 2.

One of the main concerns arising from loose nuts deals with pre-tension in the bolt. Once a nut is loose, any pre-tension in the bolt is lost and the bolt experiences a stress range of higher magnitude (due to impact as the structure vibrates) which can accentuate fatigue problems, since stress range is the most critical variable in bolt fatigue strength. The second main concern is in regard to the share of the load carried by the bolt. A bolt with a loose nut carries no load, in which case the adjacent bolts pick up that portion of the load that was carried by the bolt, thus increasing the load in the adjacent bolts. If these bolts with loose nuts go unnoticed for a long period of time, progressive failure of the other bolts can occur, leading to either complete or partial collapse of the cantilever sign support.

### Departmental Action

In response to the cited problems, and the collapse of the two cantilever sign supports, the Department issued a moratorium on the installation of these structures. The moratorium was not to be lifted until the following actions were completed: inspection of in-service sign supports, fracture analysis of the failed anchor bolts, and analysis of the current design including the effects of vortex shedding.

Inspection. Beginning in early 1990, the over 1,200 in-service cantilever sign support structures were inspected and the job was completed within two weeks. This inspection included sounding the nuts of the anchor bolts for tightness, and a visual check of the structures' components. When the anchor bolt nuts are struck sharply with a hammer, a recognizable 'ping' occurs if they are properly tightened. During inspection, if this sound was not present when the anchor bolt nuts were struck, they were considered loose and subsequently tightened with a large wrench. A follow-up program was instituted that involved the ultrasonic testing (UT) of all anchor rods on MDOT's cantilever sign structures. During UT inspection of the anchor bolts, if a flaw was found, the cantilever would be taken out of service to ensure a safe highway. These inspections, by the way, will continue for years to come.

Fracture Surface Analysis. The Department hired Dr. John Fisher, of Lehigh University, a nationally known expert on fatigue failures, to do a fractographic analysis of the

**Materials and Technology Engineering and Science**

MATES is a news bulletin authorized by the transportation director to disseminate technical information to MDOT personnel, and is published by the Materials & Technology Division. The cost of publishing 800 issues at $0.05 per issue is $40.00 and it is printed in accordance with Executive Directive 1991-6.

four failed anchor bolts from the cantilever sign support that collapsed in February 1990. During his analysis, it was noted that the telltale signs of fatigue failure were present, and these provided a history of the crack growth. Dr. Fisher calculated the stress ranges the anchor bolts experienced during progression of the crack and found them to be between 10 to 12 ksi for the fracture below the bottom nut and 10 to 15 ksi for the fracture at the concrete base. Dr. Fisher concluded that vortex shedding was the likely cause of the fatigue failure and that wind blasts from trucks passing under the sign support could also be a possible contributor. These calculated stress ranges were then used as a basis to develop the model that would be used in the analysis and redesign of the cantilever sign support structures.

Analysis of Current Design. In order to include the effects of vortex shedding in the analysis of the sign support structure, the vibrational and aerodynamic characteristics of the structure were investigated. A finite element program was used to determine the vibrational characteristics of the structure. This included calculation of the mode of vibration, along with the associated natural frequency of that mode. It was determined through this finite element analysis that two basic modes of vibration are experienced by the sign support (Fig. 3).

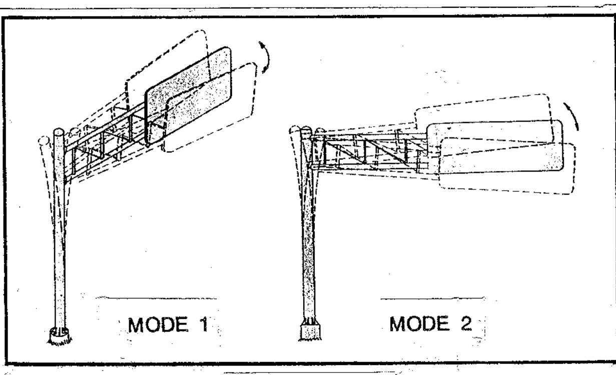


Figure 3.

The fundamental mode of vibrations is a rotational mode whereby the horizontal arms pivot about the vertical upright in a horizontal plane with a natural frequency of just over 1 Hz (Hertz, or cycle/second). The second fundamental mode of vibration is a rocking motion in the plane parallel to a sign with a frequency of just under 2 Hz. This approach to determining the vibrational characteristics of the sign structure had been verified by previous research.

These sign support structures are actually considered in the design process as non-aerodynamic and are classified as a 'bluff body.' This means, in effect, the height of exposed surface to wind is greater than, or equal to, the depth of the structure subjected to the wind flow. In this case, under certain circumstances, the wind flow can create vortices behind the structure as cited above in the example using the straw. In order to describe the frequency of this vortex shedding on various shapes, testing has been done to determine what is known as a Strouhal number (named after a mid-19th century scientist). This Strouhal number is dependent upon the shape of exposed surface and indicates the frequency that vortices are created. The sign structure itself is composed of various components: the vertical upright, the horizontal arms, and the panel itself. Each of these has a slightly different Strouhal number, but they are close enough to permit the structure to act as an entire unit.

Applying these investigations led to formulas that would be used in the development of the model to include vortex shedding. Two cases for the analysis were developed based on these formulas because the fundamental frequencies were fairly close together and it was believed that there was an interaction between the two. The first case used the second fundamental mode shape; i.e., the rocking motion that creates axial tension in the anchor bolts. The calculated stress range in the anchor bolt farthest away from the roadway was 9.2 ksi, which compares reasonably well with that calculated in the fractographic analysis by Dr. Fisher (10 to 12 ksi). In the second case, the analysis combined the effects of both the first mode (rotational mode) and the second mode (rocking mode) of vibration. This type of vibration, or interaction between the two modes of vibration, creates a combined axial tension and bending in the anchor bolts. Combining the two modes of vibration indicated a stress range of 11.7 ksi. This compares favorably with that calculated by Dr. Fisher (10 to 15 ksi). It is interesting to note that the critical wind velocity calculated by this analysis was between 10 to 15 mph.

Direct wind blasts from trucks passing under the sign panel were also investigated. The model used for this case was based on previous research. Using a 30-mph wind gust in a triangular-shaped distribution on the sign panel, the calculated stress range experienced by the anchor bolts was 3 ksi. This indicated that truck wind blasts would not control the fatigue design, although they could certainly contribute to crack growth once a fatigue crack was initiated by vortex shedding.

Using the model cited above, which included vortex shedding, all the different types and sizes of cantilever sign support structures were analyzed for anchor bolt fatigue and a new specification written. In several cases larger diameter anchor bolts were required. Finer pitch threads on the anchor bolts were specified, which allows easier tightening of the nuts and lessens the chance for loosening. Toughness requirements for the anchor bolts were also included in the new specification. This toughness requirement will permit a crack to propagate before fracture occurs and allow time for inspection to find any flaws before they become critical.

A bolt tightening procedure was included in the specification. This bolt tightening procedure is similar to that used in tightening the lug nuts on the wheel of a car. Turning the nut 1/3 turn past the snug position was instituted as a bolt tightening procedure to ensure proper tightness of the nut and to prevent loosening of the nut. This tightening procedure also has the beneficial effect of increasing the fatigue resistance of the anchor bolt (capable of withstanding more cycles of a given stress).

An erection procedure was instituted consisting of sequentially fastening the components in place, instead of erecting the entire structure after assembly on the ground, as many contractors were doing. This new procedure facilitates tightening of the anchor bolts by limiting the dead load effects of the structure during tightening. After the plans and specifications were revised, the moratorium on the installation of cantilever sign supports was lifted in October 1990.

In an effort to verify the models used in the analysis of the current cantilever support structures, two sign structures were instrumented and modeled by Materials and Technology personnel. The first instrumented sign support was on I 96 just west of Lansing. Strain gages were mounted on the anchor bolts, along with accelerometers and a wind speed indicator mounted on the structure itself. The second instrumented sign support was placed near the maintenance warehouse at the State Secondary Complex near Dimondale. Strain gages were again mounted on the anchor bolts with accelerometers and a wind speed indicator. This investigation of in-service sign supports is ongoing, but interim results indicate that the model used for the analysis to include vortex shedding is reasonable and correlates with observable wind-related stresses.

The investigation also showed that truck wind blasts are of little consequence and do not control the fatigue design. Vortex shedding has been observed in the instrumented sign at the Secondary Complex and the stress range indicated is reasonably close to that calculated. National research in this area will begin in 1993 under a National Cooperative Highway Research Program (NCHRP) project. This project is intended to investigate the fatigue design and evaluation for light standards and sign supports. Vortex shedding models, anchor bolt fatigue, and structure redundancy will be included in the project.

-Roger Till