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](image)

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 consider 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](image)

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 in 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...
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 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.

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.

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