REDUCING THE RISK OF CATASTROPHIC BRIDGE FAILURES

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The public and engineers alike have become accustomed to the use of a factor of safety to prevent failures. Unfortunately, such factors do not prevent catastrophic failures because of rare or unusual events or circumstances. Such failures could be caused by large floods, earthquakes, poor workmanship, inferior materials, errant sea vessels or insufficient knowledge on which to make design judgments. This paper presents a philosophy, and briefly describes methods, for reducing the risk of catastrophic bridge failures.

Catastrophic failures have a great impact on the public and the engineering profession. The collapse of a bridge, although infrequent, always makes the news headlines. Such failures are not expected because the bridge engineer is a respected public servant who has done his job well. We must keep this public trust, therefore, it is important that the subject of reducing the risk of catastrophic bridge failures be discussed at this meeting.

A catastrophe, according to the dictionary, is any great and sudden calamity, disaster or misfortune. The collapse of a bridge is a catastrophe. Catastrophic failures of bridges are caused by: (1) the occurrence of unusual or rare events such as floods or earthquakes, (2) the limited understanding of our materials and engineering principles, (3) failure to provide adequate maintenance or timely replacement (4) load limit violations or (5) impact from naval vessels.

In reducing the risk of failures, one might conclude that this can be accomplished by increasing the factor of safety. No, this reduction of risk is not necessarily one of making a bridge larger or stronger but one of designing with the recognition that the unusual and unexpected can occur and that no one individual has all the answers in this complex engineering profession.

As evidenced by all the excellent papers on new technology in the use of materials for bridge construction given at this meeting, we are making tremendous progress in designing new type structures and in doing a better job on our conventional designs. Nothing in this discussion on reducing the risk of failures should detract from the technical experts who so ably have made such significant contributions. We need, however, to recognize that catastrophic failures are a concern of all of us and we must cope with this eventuality in the design of a bridge and throughout its service life.

Unfortunately, it took the failure of the Silver Bridge over the Ohio River in 1967, killing 46 people, to bring about the National Bridge Inspection Program. Inspection of existing projects is quite important and hopefully such inspections can prevent other catastrophic failures. My objective here, however, is to stress the importance of making engineering decisions from the inception of a project, as well as throughout its service life, that will give the best chance of survival of our bridge structures should the unusual and unexpected occur.

The recent failure of dams in Idaho and Georgia are good examples of the risk assumed in building such structures. There is always the possiblity of failure from rare floods, earthquakes or inadquate inspections, even though the probability of such an occurrence is small indeed. In these cases we reduce the risk of failure by doing a good job of design and construction but we must be aware that a failure can occur. It might be prudent to evaluate the alternatives of building no dam or permitting no town downstream. One can easily see by this extreme example what is meant by reducing the risk of catastrophic failures.

The idea of reducing the risk of catastrophic bridge failures is somewhat more subtle. Possibly the best way to illustrate the point is to present several examples that might apply during plan development and operation of a bridge project, namely through the customary planning, design, construction and maintenance phases.

Planning

Good planning is essential in building a bridge. The bridge engineer should be involved in the planning process as well as in the operation of the bridge after it is completed. Some bridge engineers believed that the environmental impact statement process would give them more input into the planning and development phases. Such input should reduce the constraints in modifying structural proposals and locations as design plans develop. It is doubtful that such an ideal arrangement has come about, since many environmental impact statements tend to be quite restrictive on the designer.

The whole thought process in reducing the risk of a catastrophic failure is to evaluate the chance of a bridge to survive if the unusual occurs. Planning decisions that avoid landslides, avalanches, floods or poor foundations are steps in the right direction. Planning and design advisory panels composed of selected expertise have proven their worth over the years, particularly in designing large, new-type bridge structures. The advisory panel for the first Lake Washington floating bridge is an excellent example. One member of this panel once related that one of their major concerns was whether or not the concrete pontoons used could be built to withstand water for a long period of time. One wonders if this concern over such a mundane matter did not have some bearing on the fact that you can sweep dust in the cells of the pontoons after 40 years of service. To further emphasize the desirability of setting up of such panels, the designer of the more complicated Hood Canal floating bridge did not have the benefit of a panel and the project nearly ended in a catastrophic failure of both the bridge and the chief engineer.

Design

As a result of the planning process, the bridge engineer usually has to accept some compromise to his idea of the ideal solution. Hopefully the planning decisions provide for some latitude to study alternatives as the more detailed design develops. Crossing a river usually offers no compromise, but where and how we cross usually give some latitude on the selection of the location and grade of a structure.

In considering a reduction to risk of failure stream crossings are particularly important because of the number of bridges lost annually due to floods. Many are designed to pass 50- or 100-year floods, but larger floods are usually the cause of a washout. It is time we stand back and look at our designs and follow the suggestion of one college professor when he tells his students to ask, "What if?" What if a larger flood occurs (and it will)? What if there is a flaw in my material or my workmanship is poor? In answering these questions, must I admit that my structure will collapse or will I just have a minor repair?

Providing structures adequate to pass rare floods and maintain traffic at the same time is both difficult and uneconomical. It is then a challenge to construct a crossing that accommodates the rare flood with minimal damage. Such designs mean providing waterway over bridge approaches, building relief openings and even submerging the bridge itself. This type of design has worked satisfactorily in the past, and more common use of such features can do much in reducing the risk of catastrophic failures.

What is involved in designing a crossing that can accommodate such large floods? First, the designer must have a good concept of the hydraulic principles of stream flow, the characteristics of stream scour (realizing the limitations in the state-of-the-art), the effects of bridge and approach geometry on flow and an appreciation of problems caused by drift and debris. This knowledge must be applied to design the many features of the entire crossing or our bridge could be washed out before overflow is accomplished. Some of the features to be considered are: pier type and orientation, use of spur dikes and abutment treatment, pile penetration, size and location of main span and relief openings, and resistance of the structure to forces of water and debris, including floatation. Usually each crossing has a unique set of problems. Often the type of construction proposed here is not a matter of more cost, but rather more design time and much engineering ingenuity.

Another design aspect that is less obvious than floods, but nevertheless a major factor in catastrophic failures, is the problem of the brittle fracture of critical structural members. Recently there have been several failures of such members, nearly causing complete collapse of major bridges. The risk of this type of failure can be reduced in two ways: (1) avoid this type of design or (2) recognize the risk and design accordingly.

Fracture critical structural members are single load-path (nonredundant) elements of a structure whose unfailing performance is necessary to prevent collapse of the structure. As compared to a multiple load-path (redundant) member, there is no alternate member to carry the load if one of these fracture critical members should fail. Two examples of fracture critical members are the tie-girder of a tied arch and the girders of a two-girder simple-span bridge.

Obviously, safety can be built into a structure by designing a multiple-load-path system or one that can transfer load from one member to another should one break. Such a system is sometimes called a back-up system. A multiple girder superstructure is this type of system. If, however, a non-redundant system is to be built, the designer must understand the detailing of such a design and the limitations of the materials to be used. He must also understand the constraints on perfection in the construction of his project. Provisions must be made for access to critical members to facilitate inspection and maintenance.

To reduce the risk of collapse of a steel bridge containing fracture-critical members, the Federal Highway Administration is proposing a facture control plan for use by the designer, contractor and inspector. The fracture control plan specifies higher toughness steel, more stringent weld-procedure qualification and high quality inspection during fabrication.

Construction

Assuming we have an adequate design, including specifications, it then behooves us to construct the project according to plans. When fracture critical members and other vulnerable features are involved in our construction, extra-special care must be taken as to how the job is constructed. The pressures of both political and economic competition make it attractive to cut corners either to expedite the project or to make more profit. We must guard against all irregularities on projects or portions of projects identified to be critical.

The most productive and obvious way to construct a good project is through the cooperative efforts of the contractor and the project engineer. Both of these individuals must have a thorough understanding of the project, including the identification of items that require special attention and unusual inspection. Although it is difficult to list all the steps or procedures needing attention on critical projects, the following list can be used as a guide.

1. Arrange a preconstruction conference and subsequent conferences as required to assure that all parties involved in the construction of a project are informed of responsibilities.
2. Review the contractor's schedule of work and discuss critical items with the project supervisor.
3. Check all items on the fracture control plan and confirm with the contractor the assignment of responsibilites. Quality control and quality assurance programs are an essential part of the fracture control plan.
4. All changes in plans of identified critical items should be checked by the designer before approved.

Maintenance

No mention has been made to this point about the disregard of load limits on structures as being a cause of catastrophic failures. Each year a number of drivers of large trucks ignore load-limit or clearance signs and cause bridges to collapse. Nothing in this discussion is meant to imply that we should design to eliminate the need for weight-limit controls. We know that overloads shorten the fatigue life of structures, therefore, load-limit posting commensurate with the structural strength of a bridge is important to prevent catastrophic failure.

To assure fail-safe bridges that are in service, we need adequate periodic inspections by qualified personnel. Criticial parts of each bridge, including foundation piling, fracture critical members, rockers and bearings should be identified and receive special attention in order to reduce the risk of collapse. All deficiencies at critical locations should be reported, evaluated, and remedial action taken for immediate repair or possible closure of the structure. It must be stated that periodic inspections of existing bridges is an important step toward preventing catastrophic bridge failure. Also, inspections during and after highwater have helped considerably in correcting deficiencies.

Recently we have experienced a rash of bridge failures from the impacts of large ships and barges. Fender systems, navigation aids, warning devices and clearances must be maintained as an effort to protect our bridges from such catastrophic failures. Navigation controls, passage clearances, and pier fendering systems are subjects needing further study and research.

Conclusion

In the short time of this presentation you have thought of some additional ways you could design your bridges to give them a better chance of survival. Only highlights have been presented here. Designing to withstand earthquakes is certainly a subject worthy of consideration. Avalanches, earth slides and wind deserve some attention too. None of us, as individual engineers or collectively as a profession, want our structures to fail. We cannot predict the so-called "Acts of God," but we can minimize their impact.