Bridges Are Expensive—Bridge Failures Are More Expensive

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The failure of the New York State Thruway Bridge over Schoharie Creek demonstrated once again that bridge failures are more expensive than just the bridge itself, and that it would be prudent to assess the vulnerability to floods of all existing bridges over alluvial rivers. All such bridges are vulnerable to some degree unless they have been built by design or by engineering judgment for the maximum flood to be expected and the worst geometry and flow conditions that may come into being during the life of the bridge—and with proper evaluation of all factors. The remedial measures needed to make an existing vulnerable bridge virtually invulnerable will probably cost more than comparable measures would have cost at the time it was built; but, nevertheless, the cost can probably be justified when life and limb and a year or two of traffic delay are considered. That nothing has ever happened to a bridge that is 25 or 50 years old may be just a matter of luck, and it is not a sufficient reason to not assess the vulnerability of the bridge. Luck can run out, and the failure of an old bridge can still be very costly.

Bridges are expensive. Therefore, one might expect a prudent man (or organization) to build bridges so there will be only a minimal chance of failure during their anticipated useful life. More precisely, the added costs of building a more secure bridge should be balanced against the product of the total cost of a failure times the probability of that failure. The fact that none of the three factors is known with complete confidence is not a reason to do nothing; engineers should not shirk the responsibility of making an explicit, judicious assessment of the risk to be taken. The world is a dangerous place and man's knowledge is limited: therefore, some risk must be taken. However, bridge failures are more expensive than the bridge itself, as evidenced by the total cost of the failure of the New York Thruway Bridge over Schoharie Creek. The small risks of unusual events should be assessed and the cost of building to stand, even if an unusual event occurs, should be thought of as an insurance policy.

THE PROBLEM

Bridges can fail in any of several ways:

1. The live loads imposed on a bridge—legally or illegally—can be much greater than anticipated in the design.
2. The materials of which the bridge is made can deteriorate so their strength is reduced.
3. An earthquake greater than considered in the design can occur.
4. The earth on which the bridge is built can sink or slide.
5. If the bridge crosses a stream and is not founded on bedrock, the stream bed around the piers and abutments can be scoured out, destroying the ability of the foundations to support the bridge.

The first of these reasons for failure can only be reduced by the education of legislators and the enforcement of laws. The second, and possibly the fourth, hopefully should be noticeable during the bridge inspections that have been conducted regularly since the tragic failure of the Silver Bridge over the Ohio River. The third and the fourth can be the subject of re-analysis when and if additional information on earthquakes or landslides become available. Few bridges fail for these first four reasons, and those that do are usually old and are likely to be obviously vulnerable.

It is the fifth reason for bridge failures—floods—that is at issue here. More bridges fail in floods than in any other way, and their vulnerability is not apparent in routine inspections. The vulnerability of a bridge to floods can only be assessed by (1) determining the magnitudes of the floods that could occur, (2) imagining the changes that might occur in the channel reach sometime in the future, (3) delineating the flow pattern through the bridge, and (4) estimating the scour and lateral forces that could result in the failure of the bridge. In the case of a new bridge, there is little doubt that the bridge should be built so it will not fail, although the best way to build the bridge may not be clear. In the case of an old bridge, a greater risk might have to be accepted because of the limited further useful life of the bridge and because of the difficulty and cost of making the old bridge secure.

THE DESIGN FLOOD

One thing that is clear is that the 100-year flood rule for design is simply not good enough. The 25 (or 50) year nominal life of a new bridge means that there is a 25 percent (or 50 percent) chance the bridge will fail in a flood of greater magnitude than the 100-year flood. Making the bridge invulnerable to the maximum flood that can be expected will not increase the cost by 25 percent or 50 percent. The lesser useful life of the old bridge may result in the 100-year flood being the flood to be resisted—if the value of the bridge is the only loss considered. But if life and limb and a year of traffic delay are included in the losses considered, remedial work to enable the bridge to resist a rarer flood can probably be justified.

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It should be noted here that the first and most unrealistic guess would be the infinite flood as posited by almost all mathematical expressions used in hydrologic flood-frequency analysis. A bridge cannot be designed to withstand an infinite flood. However, there can always be a question whether or not some large, but finite, flood could be exceeded. The best evidence of realistic maximum floods that can be expected, but probably will not be exceeded, is being obtained by the geomorphologists who have been studying paleofloods.

INSURING THE INVESTMENT IN BRIDGES

The total investment in bridges in any state is a truly large sum. Some of these are not over waterways, and some of those over waterways are not by any stretch of the imagination vulnerable to floods. But bridges over alluvial streams which are founded on the alluvium are vulnerable to some unknown degree. It would be prudent to assess their vulnerability, and it would be wise to decrease that vulnerability if possible and justifiable.

Can one be absolutely certain that a bridge has been made invulnerable to floods? Not if mere best guesses are made as to the maximum expected flood flow, the future character of the river channel, the hydraulics of the flow, the amount of debris, and the predicted scour. Only if unrealistic guesses are made of all these factors could one feel *absolutely* certain that the bridge has been made invulnerable. That certainty, however, would have been achieved at a cost that may be unreasonable. It should be possible to compare the cost associated with the best guesses and the cost associated with the unrealistic guesses. And then consider whether there is something better to do with the extra money—say, some other safety measures in the transportation system that would save lives.

NEW BRIDGES

For new bridges the best solution will usually be to deepen the foundations to accommodate the scour predicted in the worst case because it is only the extra length of pile or caisson, or deeper spread footing, that results in added costs—the construction plant is in place. However, this is not to imply that alternative (and innovative) designs need not be considered; there will be opportunities to save by optimizing the foundation (and perhaps bridge) design.

OLD BRIDGES

For old bridges, a number of solutions are possible, including:

1. Riprap at the level of the bottom of the deepest (future) scour hole for which the present foundation is adequate.
2. Spur dikes to move the scour hole away from vulnerable abutments.
3. Channel improvements to improve the hydraulics of the bridge opening.
4. Additions to the present foundation (such as a sheet pile ring).
5. A new foundation.
6. A low dam or drop structure downstream of the bridge to raise the stream bed under the bridge.
7. Adding spans to the bridge.

These solutions are listed roughly in order of cost, and it is readily apparent that the last solutions can cost as much as the bridge is worth. Therefore, it is also obvious that the first solutions would be preferred if spur dikes or other remedial work would stay during a big flood and would function properly. However, enough is known now to go ahead with assessments and remedial work—there will always be a need to know more.

OTHER FLOOD PROBLEMS OF HIGHWAYS

It should be noted that the discussion here has referred only to the bridge, not to approach embankments or roads parallel to the river, or culverts. These are separate problems—similar, but different. They should also be investigated, but the urgency for remedial measures is less for one simple reason. Bridges, when they fail in a flood, are likely to fail quite suddenly with little or no advance notice because the scour hole cannot be seen through the muddy flood waters. Approach embankments, parallel roads, and culverts should usually give evidence of impending failure—if someone will only look. Therefore, since everything cannot be done at once, the priority should be given to the bridge problem, and when that is in hand, attention can also be given to the other parts of the transportation system which may be vulnerable to floods.

A PROGRAM TO ASSESS THE VULNERABILITY OF BRIDGES TO FLOODS

A program to assess the vulnerability of bridges to floods needs to address several issues more or less simultaneously—some of which may have been studied by someone in the past:

1. Development of one or more flood magnitude-frequency-watershed area relations with special emphasis on the maximum expected flood magnitudes.
2. Accumulation of evidence of changes in channels in regard to plan form and aggradation and degradation.
3. A tentative, quick examination of the bridges over alluvial rivers to separate them into (a) those hopefully not vulnerable to floods, (b) those probably vulnerable to floods, and (c) those that may or may not vulnerable to floods.
4. A careful examination, first, of the bridges probably vulnerable to floods and the recommendation of measures that should be taken to make them less vulnerable (or invulnerable) to floods; eventually, all bridges should be checked.
5. Adding to the routine bridge inspection program, observations and standard photographs of the channel characteristics upstream, through, and downstream of the bridge.

Once the bridges have been assessed, it should not be necessary to repeat the assessments unless (a) new evidence of flood magnitudes are obtained, (b) new evidence of possible channel changes are obtained, (c) improved methods of predicting the hydraulics of flow or the expected scour become available, or (d) the routine bridge inspections provide evidence of channel changes not already considered.

The assessment program would be expensive; remedial measures would cost more. However, the losses which would not occur should result in an overall savings to the transportation system in the long run. In addition, the traveling public and the responsible officials would have peace of mind.