The 1999 Taiwan Earthquake

BRIDGE DAMAGE

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Highway damage was widespread throughout Taichung and Nantou counties due to fault rupturing, collapsed or crippled bridges, landslides, soil settlement and slope failures. Ten days after the earthquake, 45 kms of road remained closed, and another 400 kms, while open to traffic, were subject to delay and capacity restrictions (Figure 1).

Many hundreds of bridges are located in the Taichung and Nantou counties but most escaped serious damage and suffered only minor distress such as the settlement of approach fills behind abutment back-walls. But approximately 10% of the bridge inventory experienced moderate-to-major damage and those most seriously affected range from 3-span to 28-span structures, including simply supported reinforced concrete slab-and-girder superstructures, continuous steel plate–girders and long-span cable-stayed girders.

For example, Route 3 is a major north-south highway running the length of Taiwan from Taipei in the north to Pingtung in the south. There are approximately 65 bridges on this route as it passes through Taichung and Nantou counties. Five of these bridges suffered collapsed spans or were extensively damaged, such that the safety of the structure was in jeopardy, requiring closure pending demolition or significant repair. Another five bridges on county and city highways experienced similar distress, including new cable-stayed bridge. Table 1 gives a summary of the pertinent data for these ten bridges. Figure 1 shows their approximate locations on Routes 3, 129 and 149, and their proximity to the epicenter at Chi-chi and the Chelungpu fault. All are considered to be in the ‘near field’ and thus subjected to intense ground motions both horizontally (up to 1 g) and vertically (up to 0.4 g), and average fault dislocations of approximately 1.5 m horizontally and 3 m vertically.

Damage to these ten bridges included: overturned bearings; shear failures in columns, pier walls, and caissons; joint failures in column-to-girder connections; loss of support for both normal and skewed simple and continuous girders; cable fracture; abutment back-wall failure; and foundation failures due to slope instabilities, liquefaction, and fault rupture. Figures 2, 3, 4, and 5 illustrate some of this damage.

LESSONS LEARNED

The following set of lessons learned includes new lessons, not previously seen so clearly, and some old lessons that are to be remembered.

- Fault rupture, directly under or between bridge foundations, is a catastrophic event and span collapse is inevitable if the dislocations are large.

![Figure 1. Highway closures and bridges with significant damage in Taichung and Nantou counties.](image)
Near-field ground motions are intense and extremely punishing on bridge structures, particularly older bridges that have not been designed to modern codes. Long-span bridges are vulnerable in near-field sites. Ground failures precipitate structural failures. Engineered abutment back-walls and back-fills are essential to prevent span collapses even for continuous bridges.

Generous seat widths are excellent insurance against unintended actions such as ground failure and rotation in skewed spans.

Shear failures must be avoided in piers.

Engineered shear keys are required to prevent spans falling transversely from pier caps.

Load paths through column-to-girder joints must be specifically detailed, particularly for eccentric connections.

**Recommendations for Short-Term Recovery**

Recovery strategies can be divided into three classes:

- Immediate post earthquake period (1 to 90 days).
- Reconstruction of collapsed or crippled structures (3 to 12 months).
- The construction of new structures (1 year onwards).

The urgent need to reopen closed highways, immediately following a damaging earthquake, requires emergency powers to command the resources to construct bypasses around bridges with collapsed spans, erect shoring, reinstate bearings, fill and resurface settled approaches, and erect temporary bridging (e.g., Bailey bridges). All of these options are common sense and self-evident to bridge engineers and emergency management personnel.

However, when design commences for the replacement structures (the reconstruction phase), it is not always clear how to proceed. It is unlikely that the causes for collapse and sustained damage will be fully understood and agreed at this time. Yet the design process cannot wait until all the answers are known and must proceed. It is therefore recommended that a conservative strategy be adopted for the reconstruction phase, to minimize the risk of repeating past deficiencies. For example, seat widths may be arbitrarily increased, shear keys strengthened for elastic response, shear and confining steel increased in columns, skew supports removed (or seat widths further increased to allow for skew), eccentric column to cross-girder connections eliminated, sacrificial spans installed in bridges that cross active faults, and site specific hazard analyses performed for critical bridges, including long-span bridges.

As agreement is reached on the causes of damage, and improved design methodologies developed, the conservatism in the above approach might be relaxed, and the bridge design code revised for all future construction. A moratorium on new construction might be considered until the revised code is available. But this may take several years to complete, and an interim set of guidelines might be preferred instead of a moratorium. Such a set of guidelines might be based on the conservative procedures used for the reconstruction phase.