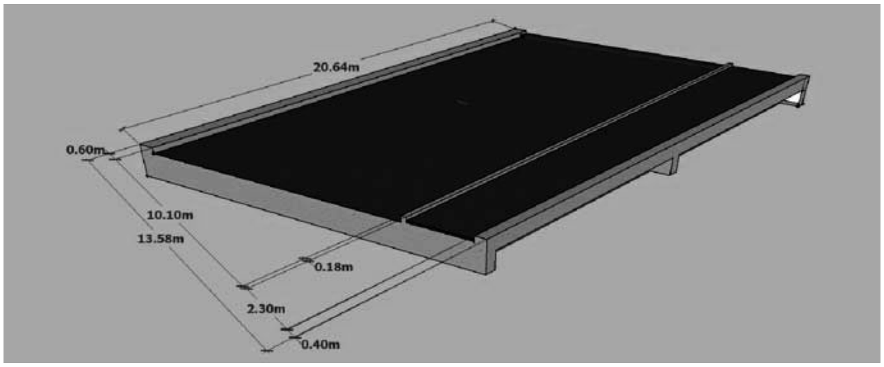
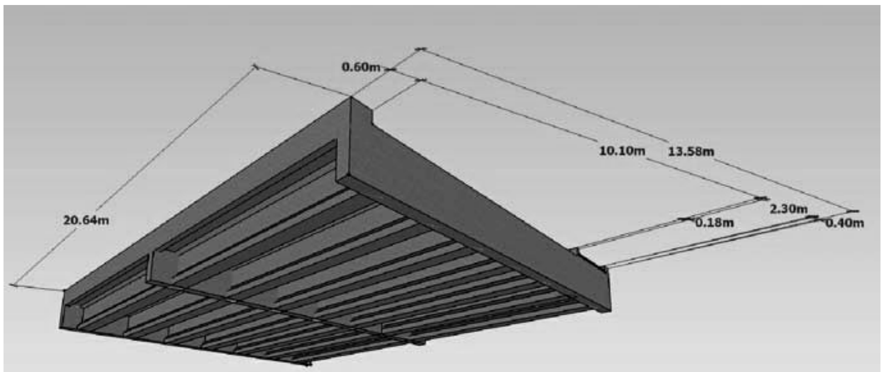
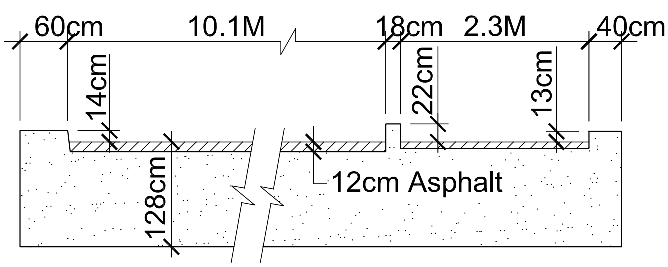


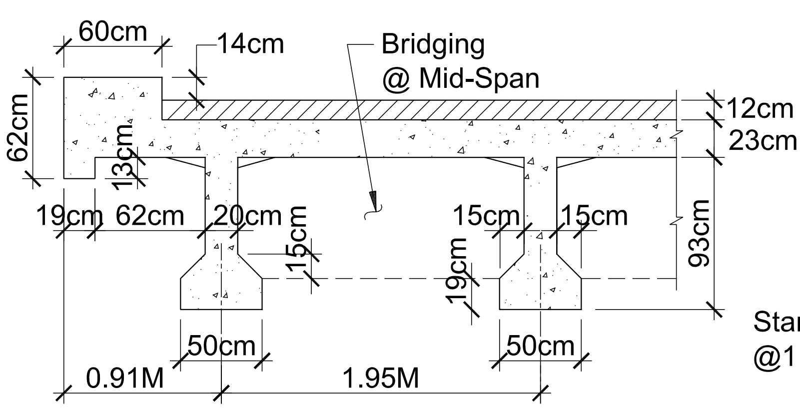
DIMENSIONS @ TOP OF BRIDGE



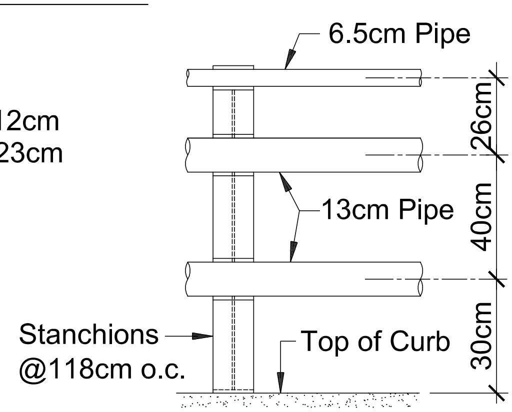
DIMENSIONS @ BOTTOM OF BRIDGE



END ELEVATION @ BULKHEAD



BRIDGE DECK SECTION

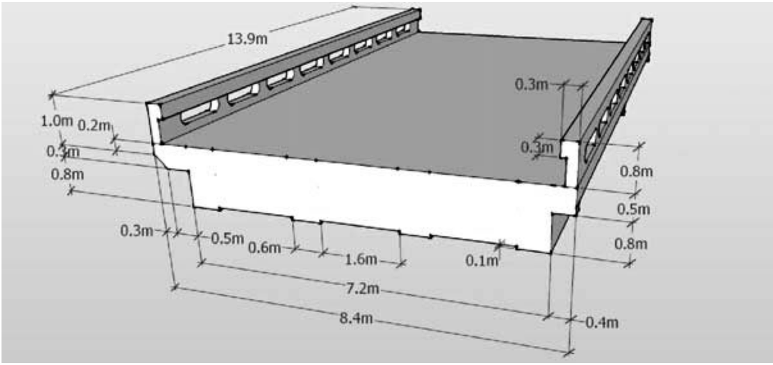


YIELDED SAFETY BARRIER DIMENSIONS

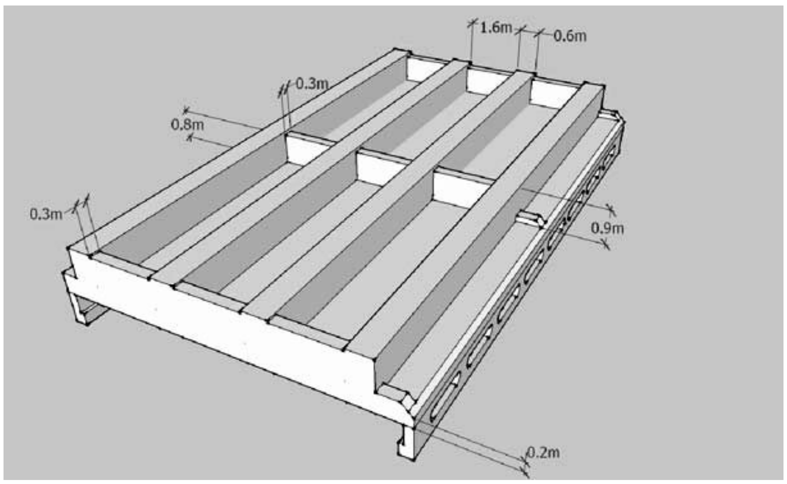
BRIDGE OVERPASS OUTAGE
- RIKUZENTAKATA
141°38'58.07" 39°0'31.40"

EXHIBIT 9-2b

IAN ROBERTSON



BRIDGE DIAGRAM (RIGHT SIDE UP)

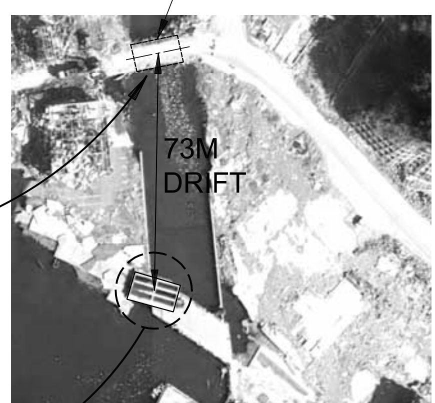


BRIDGE DIAGRAM (UPSIDE DOWN)

LOCATION PLAN
(© 2011 Google)

Temporary Bridge Constructed @ Original Bridge Location

VIEW @ ORIGINAL LOCATION
(Chock)



VIEW @ CURRENT LOCATION
(Chock)

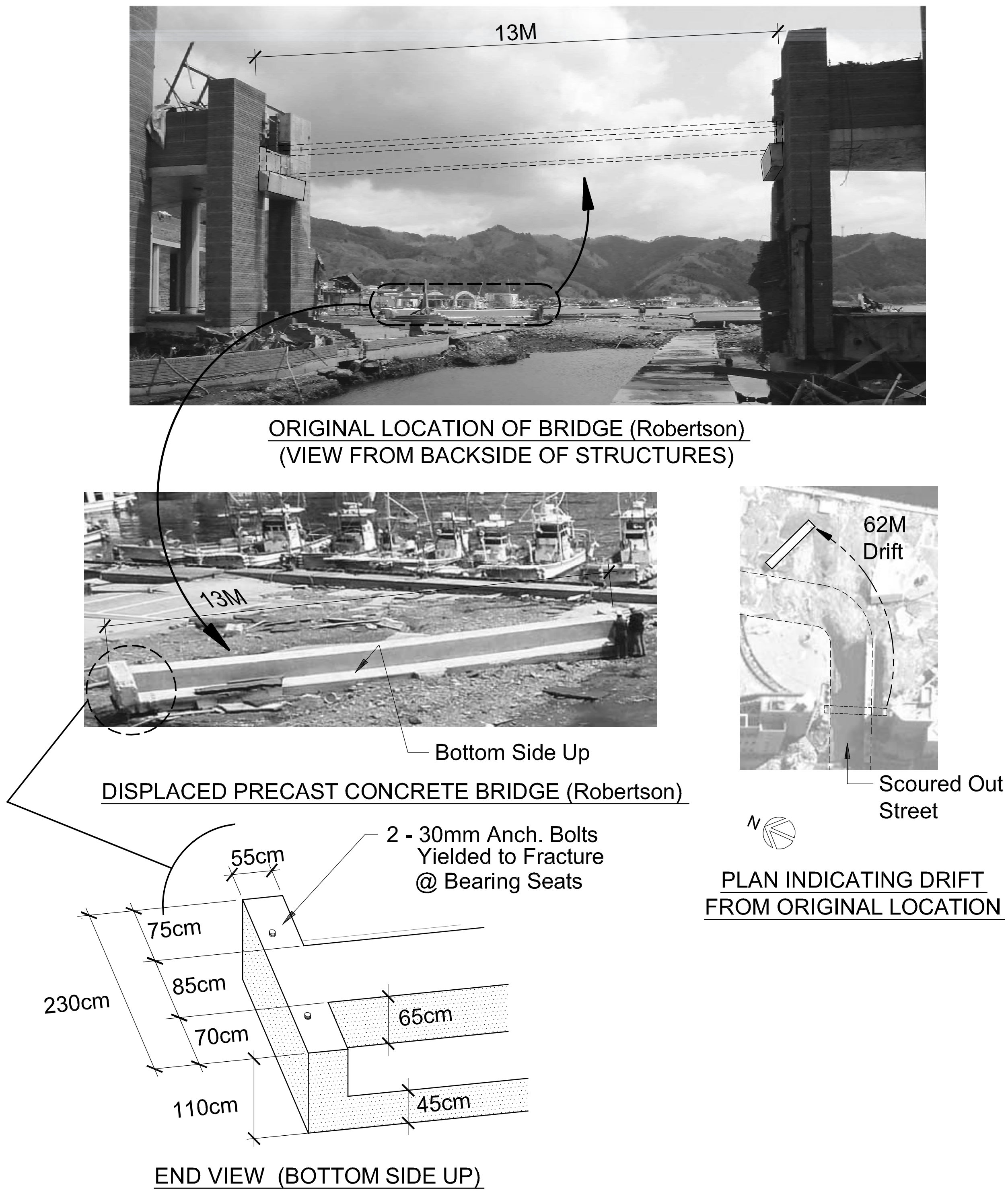
PLAN INDICATING DRIFT
(© 2011 Google)

NOTES:
Buoyancy likely added to failure
Relocation was Seaward of original location
(Indicating movement during drawdown return flow)

FLIPPED BRIDGE - ONAGAWA
141°26'56.71" 38°26'45.70"

EXHIBIT 9-3

DAVID KRIEBEL



OUTFLOW LATERAL DEBRIS STRIKE & DISPLACEMENT TO
PEDESTRIAN BRIDGE - ONAGAWA MARINE PAL BUILDING
141°26'52.08" 38°26'32.11"

EXHIBIT 9-4 GARY CHOCK

Chapter 10
Seawalls and Tsunami Barriers

A key feature of almost every coastal area visited was a large seawall or barrier built along the coast to protect upland areas from tsunami inundation. While these walls would be effective against large wind waves in severe storm events, their primary purpose was to protect against tsunami wave impact. In general, these tsunami barriers and flood walls were one of two general types: (1) vertical or inclined concrete structures or (2) compacted earth embankments lined with concrete slabs.

Near river mouths, large sluice gate structures had been built to allow normal river outflow when the gates were raised while protecting against tsunami advance upriver when closed. These sluice gates then were an integral part of the tsunami defense plan along with the coastal tsunami barriers and flood walls.

10.1 Vertical Concrete Flood Walls

A type of tsunami barrier that was found in several locations consisted of vertical or near vertical concrete flood walls. In most cases, these walls survived and, as a result, it was not possible to inspect their foundation systems. Given the intense lateral forces and degree of scour that these walls withstood, it is likely they had substantial pile foundations. In one case where a concrete flood wall failed dramatically, it had a shallow mat foundation that could not resist scour and subsequent overturning.

10.1.1 Kuji Harbor

Kuji harbor was surrounded by a vertical concrete flood wall at an elevation of 8.25 m above sea level. Tsunami levels were apparently higher than the tsunami barrier as a large log and fishing net were found on top of the seawall. The basic design at Kuji featured a vertical face on the harbor side and an inclined face on the landward side, presumably to better resist overturning moments (Figure 10-1).

This wall was intended to keep the rising sea level out of upland areas in the event of a tsunami. The wall had several 10-m-wide openings to allow car/truck traffic through to the port, and each was fitted with a roller gate. These gates were 10 m long and 6.45 m (or 6.8 m) high (not 8.25 m as they extended from ground to the top of the wall). One gate observed to be missing had been transported approximately 60 m away and deposited in the harbor area on the quay wall (Figure 10-2 and Figure 10-3). The gate design seemed to rely on water pressures from the harbor to push the roller gate against the concrete wall. In this instance, however, it appeared that the fluid load that caused failure came from the opposite (landward) side and pushed the gate away from the concrete. After overtopping of the wall, the hydrostatic pressure on the landward side of the gate had not been considered in the design. This gate failure mode is consistent with those observed at other cities including Miyako, where the damaged gates lay on the seaward side of the seawall. Once the gates had failed, the impoundment behind the wall could drain, but the gate was no longer effective to prevent subsequent incoming tsunami waves from passing through the gate opening.

Figure 10-1: Kuji flood wall, viewed from landward side (Nistor)

Figure 10-2: Kuji flood wall viewed from seaward side. Note missing flood gate (Kriebel)

Figure 10-3: Displaced flood gate from Kuji flood wall (Nistor)

10.1.2 Miyako City

The tsunami barrier in Miyako is among the most famous of the post-tsunami images and videos that have been posted on the Internet. The videos showed a wall of black water, including floating vehicles and boats, which cascaded over the wall like flow over a spillway, subsequently rushing into town as the wall was overtopped (Figure 10-4 and Figure 10-5).

The tsunami barrier in Miyako is low, with a crest elevation measured at 4.1 m above sea level at the time of the site visit (April 17, 2011). The area likely had subsidence; after accounting for tidal correction, it is likely that the design crest elevation was about 5 m above sea level at the time of the tsunami. Video shows the barrier being overtopped by over 1 m. Tsunami inundation depths reached about 4 m in town behind the barrier (which became a virtual spillway).

The Miyako barrier survived in most locations with little visible damage (Figure 10-6). The barrier design is a vertical concrete wall 40 cm wide with vertical supports spaced every 10 m along the length of the wall. Despite the formation of a long scour trench on the landward side, extending about 1 m deep in places, critical foundation details could not be seen. The concrete quay fronting the barrier remained intact so that the foundation was not exposed on the seaward side. The scour trench formed 2–3 m landward of the rear of the wall, and the wall did not overturn or slide as a result of the scour (Figure 10-7 and Figure 10-8).

Figure 10-4: Aerial view of Miyako flood wall (© 2011 Google)

Figure 10-5: Tsunami crashing over Miyako City seawall (©Mainichi / AFLO)

Figure 10-6: View of Miyako seawall (Kriebel)

Figure 10-7: View of scour trench landward of Miyako flood wall (Robertson)

Figure 10-8: Additional view of scour trench behind Miyako flood wall (Kriebel)

10.1.3 Kamaishi City

Kamaishi had the lowest seawall of any town visited. The seawall was a vertical concrete structure with a top elevation of 2.1 m above sea level (Figure 10-9 and Figure 10-10). There was notable subsidence, and the harbor quay/wharf seaward of the seawall was awash (Figure 10-11). As a result, it seems likely that the original wall elevation was about 3 m. Inundation on the buildings immediately behind the wall was measured at 8.4 m above sea level. As a result, the wall was submerged by more than 6.3 m of water at one time. In general, the wall remained in functional shape with little to no scour (Figure 10-12).

Figure 10-9: Aerial view of Kamaishi flood wall (© 2011 Google)

Figure 10-10: View of Kamaishi flood wall (Robertson)