EARTHQUAKE DAMAGE TO ROADS AND BRIDGES MADANG, T.P.N.G. - NOVEMBER 1970

B. K. Ellison*

1. Introduction

This report endeavours to illustrate the damage to roads and bridges that occurred during the Madang Earthquake of 1st November, 1970. It is not proposed to interpret the damage in detail or to offer firm recommendations for future designs.

2. The Earthquake

2.1 The following information was supplied by the Port Moresby Geophysical Observatory:-

Hypocentre, Magnitude

Magnitude: ML = 7.1

Epicentre: Lat. $4^{\circ} 57'$ S. Long. $145^{\circ} 48'$ E.

Depth : 45 km

i.e. focus about 45 km beneath vicinity of Sumerang about 30 km north of Madang.

Intensities (See Isoseismal map)

- (i) Maximum intensities of MM8 or more were experienced within about 25 km of the epicentre.
- (ii) Damaging intensities of MM7 or more occurred within about a 70 km radius of the epicentre and at odd places outside this range.
- (iii) If the epicentre was north of Madang as suggested by (i), the strongest accelerations should have been east-west and vertical (from S waves with period possibly around 0.4 sec.).

Time

03.53.03 Hours Eastern Standard Time 1st November 1970.

17.53.03 Hours Greenwich Mean Time 31st October 1970.

3. General Description of Damage

3.1 Of the 47 bridges in the Madang area, all except two showed some effects from the earthquake and 29 required repair action, the damage to the other 16 being considered insignificant.

Roads in the area are generally located in the flat coastal areas and road slumping, although extensive, was generally of a minor nature. Some batter slips were found in the Madang - Mawan Road, one temporarily closing the road.

* Engineer, Department of Public Works, Territory of Papua and New Guinea.

An undetermined number of pipe culverts lost headwalls or suffered joint separation.

In the more mountainous regions remote from roads slips were extensive and loss of life due to slips occurred as far inland as the Eastern Highlands.

3.2 During the inspection, the most noticeable feature was the repetitive nature of the damage. It is proposed to illustrate the general damage by means of photographs and drawings referring to specific bridges.

Only three multispan bridges exist in the area, all single lane, of which the Gogol and the Sumerang were extensively damaged and the Gilagil suffered minor bearing failure. The rest of the bridges are single span, single lane truss or composite girder and concrete deck slab bridges.

The expansion gap in the majority of these single span bridges was closed by abutment movement. Figure 33 shows the typical end result with the holding down bolts at both ends bent against the limits of their slots and the girder hard against the end cut-off walls. In many cases the cut-off walls were cracked at the base and required epoxy grouting. Wingwalls commonly failed and could profitably be eliminated.

Since the majority of the damage appears to come from soil forces, and pendulum action appears to have been present but of little significance, future designs should most probably aim at eliminating the soil force as much as possible by introducing short approach spans.

With the longer span bridges the action of failure was more complex and these bridges will be described individually.

4. Details of Damage

4.1 Gogol River Bridge - Figures 1 to 9.

The bridge consists of a two span steel through truss, with simply supported spans of 200 ft. and 90 ft. This was the most extensively damaged of all the bridges. The 200 ft. span on the Madang side was undamaged and its abutment showed no indications of movement. The Mawan abutment however was extensively damaged. The fill level at this side is about 20 ft. above natural surface level and the abutment supported on a combination of raker and vertical steel H-piles, concrete encased (Figures 2, 3, 4, 8).

Where a steel pile was encased the

rigidity of the pin between the pile and the headstock was increased to the point where the headstock failed instead of the pile flexing (Figures 2, 3, 12). In all cases except one (Figures 24, 25) where the pile was not protected, although movement obviously occurred, no damage was done (Fig. 28).

In all bridges the tendency was for the two abutments to move towards the centre of the bridge, failing the bearings and closing the expansion joint. In the Gogol, the pier and the Mawan abutment were both founded on piles of 180 ft. penetration thru silts. It is surmised that the pier and Mawan abutment moved as illustrated (Fig. 6) failing the bearing by excessive rotation (Fig. 5) and closing the expansion gap (Fig. 7). It would appear that additional movement took place at the base of the pier after the gap had closed (Fig. 6). The Gogol is the only bridge that showed positive signs of damage to steelwork. Figure 9 shows paint flaking above slightly buckled steelwork.

4.2 Sumerang Bridge - Figures 10 to 18.

The Sumerang bridge is located almost directly above the epicentre of the earthquake so it is not surprising that this bridge should show signs of high vertical forces. The holding down bolts, when examined, show little curvature as would be obtained by failure by excessive longitudinal forces and have an almost perfect "cup and cone" typical of a tensile failure.

Of all bridges this one came closest to total failure. There was complete failure of the bearings. The free bearings had $1\frac{1}{2}$ in. diameter holding down bolts whilst the fixed bearing had 1 in. diameter bolts. As could be expected, the load went to the fixed bearing, breaking the bolts (Fig. 14, 15) and collapsing the free bearing (Fig. 16). This type of bearing (Fig. 16, 27, 30, 32) showed distress in every case and it is considered that this type of bearing is unsatisfactory for seismic regions.

One unusual feature encountered in the Sumerang Bridge was movement of the deck on the girder. This is evident in Figures 17, 18. In Figure 17 the edge of the deck has spalled above a transverse member and in Figure 18, $\frac{1}{4}$ " movement can be seen between girder and slab. Whilst re-erecting the spans it was found that no shear connectors existed, contrary to the drawings, and this permitted the movement. This was the only bridge with a concrete deck in which evidence of longitudinal distortion was observed.

As pointed out in the Gogol comments, encasing steel piles seems to cause problems. In Figure 13 cracking of the protective casing is evident. In Fig. 12 however, the protected raker pile proved sufficiently stiff to break the headstock rather than crack the protective concrete.

4.3 Rempi Bridge - Figures 19, 20, 22, 23.

The Rempi Bridge is built on spread footings. The abutments are immediately behind old abutments from a previous bridge and is founded on very fine silt. During the earthquake an immediately adjacent village was completely flattened and a good deal of the village grounds slipped almost 2 feet towards the river (Fig.

21). At the bridge, the obviously amplified ground movement caused the old abutments to collapse into the river as well (Fig. 19, 20). Longitudinal distortion was found (Fig. 22) and over 1 foot of settlement occurred at the abutment. No bearing failure was evident at this site and if better cross bracing had been provided damage would have been minor.

4.4 Murnass No. 1 - Figure 23.

This was previously an Austral truss with timber decking, simply supported on wall abutments on poor material. Under earthquake loading, the truss, not being fixed to the abutments, could not act as a strut and consequently complete collapse of the wall piers took place (Fig. 23). A temporary Bailey bridge was erected.

4.5 12.5 Mile - Figures 24, 25.

Longitudinal movement broke one pile in each abutment (diagonally opposite piles) free of their headstock (Fig. 24, 25). In both cases the pile was very close to the concrete surface and had no stirrups restraining the bursting forces.

4.6 Karim Bridge - Figures 26 to 29.

The usual failure of bearings took place (Fig. 27) breaking off the cut off walls (Fig. 29) as the two abutments moved towards the bridge centre. The steel piles were obviously flexible enough not to damage the headstock but will require some form of corrosion protection.

4.7 Gilagil Bridge - Figures 30 to 32.

This four span bridge is the longest bridge in the region. It was designed in accordance with the Highway Bridge Design Specification of the National Association of Australian State Road Authorities but nevertheless showed failure at the bearings (Fig. 30, 32).

Figure 31 indicates the extent of the pendulum movement which took place. The handrails at both ends of the bridge have both been displaced as shown. The railing to the right of the photo is connected to the abutment, the railing to the left is connected to the deck.

4.8 39.9 Mile - Figure 33.

These photos illustrate the failure that occurred at all single span composite girder and concrete deck bridges. The two photos show the bearings at either end of the one girder. In both cases the abutments moved in until the end of the girder reached the cut-off wall. The holding down bolts reached the end of their expansion slot and then bent. In some cases the concrete spalled away near the holding down bolt. The major damage was that the expansion gap closed. Since repairs can be cheaply and rapidly undertaken it is considered that this type of bearing performed satisfactorily but could be improved with minor amendment.

4.9 Road Failures - Figure 34.

Figure 34 illustrates the common road

failures. Generally slips were minor and could be attributed to excessive batter slopes. Some centreline cracking was noticeable, especially in deep fills as at bridge approaches (Fig. 1). Much more common was shoulder failure as illustrated in Figure 34. This was more common where the natural material was swampy silts. The practice of widening the road by side dumping material possibly contributed to this form of failure.

4.10 Box Culverts - Figure 35.

Box culverts performed creditably with only one failure. In this case all interior walls cracked as shown (Fig. 35) with the crack widest on the north face of the wall and of hair crack dimension on the south face. The end walls were extensively broken with movement towards the centre of the culvert being evident. The damage indicates that the deck, which is under fill, moved towards Madang with sufficient force to fail the walls.

5. Acknowledgements

Acknowledgement must be given to the Staff of the Department of Public Works' Madang office who were unfailingly helpful during the investigation of the damage. Faced with extensive damage to water supplies, housing, roads and bridges, the Regional staff worked with determination and diligence to reduce the inconvenience to the public to a minimum and still found time to assist in the investigations.

Acknowledgement must also be given to the Principal Engineer Roads and Bridges, Mr. C. J. Best, for his assistance during the preparation of this report and for the bulk of the photos used to illustrate the damage.

The permission of the Departmental Head of the Department of Public Works and of the Administrator of the Territory of Papua and New Guinea to prepare and submit this paper for publication is gratefully acknowledged.

MADANG NORTH COAST ROAD

Piles driven between 50 ft. and 90 ft. into silt, sand-silt or silty clay overlaying coral or silt stone.

GOGOL RIVER BRIDGE

Piles driven to 180 ft. in silty sand or silty clay

LEGEND

Humic Brown Latosols / Gleyed Pelosols / Rendzinas
 Regosolic Brown Soils / Acid Brown Forest Soils
 Latosolics / Laterites
 Alluvial Soils / Half Bog Soils
 Brown Forest Soils / Pelosols
 Brown Forest Soils / Regosolic Brown Soils

hBL/gP/R
 Reg/aBf
 L/La.
 Al/hB.
 Bf/P.
 Bf/Reg.

From Soil Map of New Guinea C.S.I.R.O. 1962-1965

PRELIMINARY ISOSEISMAL MAP OF THE MADANG EARTHQUAKE (1st Nov. 1970)

1. GOGOL BRIDGE - SETTLEMENT BEHIND SOUTH ABUTMENT.

2. GOGOL BRIDGE - NOTE EXTENSIVE CRACKING OF ABUTMENT AT "PIN" BETWEEN HEADSTOCK AND PILES.

3. GOGOL BRIDGE - WINGWALL FAILURE... THIS FAILURE WAS COMMON TO MANY OF THE BRIDGES WITH WINGWALLS.

4. GOGOL BRIDGE - DETAIL OF THE SPALLING OF CONCRETE AT THE HEADSTOCK PILE INTERFACE.

5. GOGOL BRIDGE - EXCESSIVE LONGITUDINAL MOVEMENT BROKE RETAINERS AND ROTATED PIN AS SHOWN.

7. GOGOL BRIDGE. THE TENDENCY IN ALL BRIDGES WAS FOR ABUTMENTS TO MOVE IN AND CLOSE EXPANSION JOINTS.

6. GOGOL BRIDGE.

8. GOGOL BRIDGE. CORROSION PROTECTION WAS REMOVED TO REVEAL UNDAMAGED STEEL PILES.

9. GOGOL BRIDGE. PLATE BUCKLING. ONE OF THE FEW SIGNS OF DAMAGE NOT ATTRIBUTABLE TO SOIL MOVEMENTS.

10. SUMERANG BRIDGE. NOTE DISPLACEMENT OF BRIDGE ON THE CENTRE PIER AND A FILL SETTLEMENT AT ABUTMENT.

11. SUMERANG BRIDGE BOTH CUT-OFF WALLS WERE BROKEN BY VIOLENT LONGITUDINAL MOVEMENTS.

Crack extends
full width of
headstock

12. SUMERANG BRIDGE. CONCRETE ENCASED STEEL RAKER PILES BROKE HEADSTOCK AS SHOWN.

13. SUMERANG BRIDGE ABUTMENT CONCRETE ENCASING
CRACKED AND THE HEADSTOCK DAMAGED SAME AS GOGOL.

14. SUMERANG BRIDGE FIXED BEARINGS. 1 INCH BOLTS
APPEARED TO FAIL IN TENSION RATHER THAN SHEAR.

15. SUMERANG BRIDGE ABUTMENT. TOTAL RELATIVE OF MOVEMENT
SUPERSTRUCTURE AND ABUTMENT WAS 16 INCHES.

16. SUMERANG BRIDGE PIER BEARINGS. AS ILLUSTRATED, FAILURE OF BEARING ALMOST CAUSED LOSS OF SPANS.

17. SUMERANG BRIDGE. DECK WAS NOT CONNECTED TO GIRDERS ALLOWING RELATIVE MOVEMENT AND SPALLING OF CONCRETE.

18. SUMERANG BRIDGE. NOTE EVIDENCE OF MOVEMENT BETWEEN DECK AND GIRDERS.

19. REMPI BRIDGE. WALL ABUTMENTS FROM PREVIOUS BRIDGE FELL INTO RIVER. TRUSS FOOTINGS SETTLED BEHIND.

20. REMPI BRIDGE.

21. REMPI VILLAGE. MANY NATIVE VILLAGES WERE DAMAGED, THIS VILLAGE SLID TOWARDS THE ADJACENT RIVER.

22. REMPI BRIDGE. TIMBER DECKING ALLOWED LONGITUDINAL DISTORTION.

23. MURNASS NO.1. WALL PIERS COMPLETELY FAILED CAUSING THE LOSS OF THIS BRIDGE.

24. 12.5M BRIDGE. LONGITUDINAL FORCES BROKE DIAGONALLY OPPOSITE PILES FREE OF THEIR HEADSTOCKS.

25. 12.5M BRIDGE.

26. KARIM BRIDGE. NOTE SETTLEMENT OF APPROACH FILLS.

27. KARIM BRIDGE. ROTATION OF THE BEARINGS STOPPED ONLY WHEN THE GIRDERS HIT THE CUT-OFF WALLS.

28. GILGIL BRIDGE.

29. KARIM BRIDGE. NOTE COMPLETE RUPTURE OF END CUT-OFF WALLS.

30. GILAGIL BRIDGE.

31. GILAGIL BRIDGE.

32. GILAGIL BRIDGE. NOTE BEARING ROTATION, AND EARTHQUAKE CREATED DEBRIS AGAINST PIER.

33. 39.9M BRIDGE. THIS SHOWS MOVEMENT OF BOTH ABUTMENTS TOWARDS BRIDGE CENTRE.

34. TYPICAL ROAD FAILURE.

35. BOX CULVERT WALL FAILURE.