Copy 4

COMMONWEALTH OF AUSTRALIA

DEPARTMENT OF NATIONAL DEVELOPMENT

BUREAU OF MINERAL RESOURCES, GEOLOGY AND GEOPHYSICS

Record No. 1968 / 140

Report on Earthquake Engineering Problems in The Territory of Papua & New Guinea, Including Strong-Motion Recording

by

R.I. Skinner

Record No. 1968 / 140

Report on Earthquake Engineering Problems in The Territory of Papua & New Guinea, Including Strong-Motion Recording

by

R.I. Skinner

CONTENTS

FOREWORD

The author was retained by the Bureau of Mineral Resources (BMR) to make a general assessment of the earthquake engineering problems in the Territory of Papua & New Guinea.

On the basis of this assessment he was to advise BMR on the setting up and operation of a strong-motion earthquake recording network.

The author spent two days with BMR and then two weeks in the Territory taking part in discussions and also travelling widely to inspect existing structures and proposed sites.

When back in Canberra he presented a preliminary report which contained firm recommendations on the setting up and operation of a network of strong-motion accelerographs. Comments on other earthquake engineering problems of the Territories were included in the report, "Preliminary Report on the Earthquake Problems in the Territory of Papua and New Guinea, including Strong-Motion Recording." (BMR Record No. 1967/111).

The present report confirms the recommendations made in the preliminary report, discusses the reasons for them, and also makes some suggestions on steps which may be taken to implement the proposals.

The author wishes to express his gratitude to the Director of BMR and his staff for their help and hospitality. Many members of the TPNG Administration and of BMR contributed to a fruitful and enjoyable tour of the Territory. Special gratitude is due to Dr Denham with his local and expert knowledge and his tireless and accurate staff work which enabled a very full itinerary to be completed. Great assistance was also rendered by Mr A.J. Wright, Commonwealth Department of Works, who accompanied the party for most of the tour. His technical knowledge of existing and proposed projects was invaluable.

1. INTRODUCTION

This report describes a strong-motion earthquake recording programme recommended for the Territory of Papua & New Guinea. These strong-motion records are intended to form a bridge between the earthquake data obtained by normal seismological observations and the problems of the designer of structures. Such strong-motion programmes are undertaken by all developed countries with some seismic design problems and are now being undertaken by many of the developing countries. The strong-motion data will be directly applicable to design problems. They will also greatly increase the value of earthquake damage studies and will facilitate the application of results from overseas research in earthquake engineering.

An overall picture of the earthquake engineering problems in the Territory was necessary background for the selection of a strong-motion earthquake recording programme. These general problems are outlined together with the contribution to be expected from strong-motion records.

Attention is drawn to the assistance which UNESCO is giving to developing countries in the field of earthquake engineering. The Territory of Papua & New Guinea has a strong case for assistance in this field.

2. GENERAL OBSERVATIONS

Seismic problem

Many areas of Papua & New Guinea are highly seismic. Buildings and other structures in these areas must be sited, designed, and contructed, to have a high level of earthquake resistance. Methods of earthquake resistant design cannot be adopted easily from other seismic countries. Design is a local problem for two reasons. Firstly the severity and character of the earthquake attack is dominated by the local surface layers. The deep and steeply eroded pumice near Rabaul, the coral beds at Madang, and the deep alluvial valley at Lae will each impart particular features to the ground vibrations and during very severe earthquakes will each have individual mechanisms of ground failure.

The most severe earthquake damage is normally localised in a number of small areas which are determined by the conditions of the surface layers of soft ground above substantial rock.

The second factor which makes earthquake-resistant design a local problem is the local peculiarities of building construction, dictated by local climatic, economic, and social factors. In the Territory, European-style dwellings and buildings of public assembly such as schools and churches differ greatly from their counterparts in other seismic areas. The dwellings are frequently on slender supports about eight feet high. Most schools and churches have floors which are ground-level concrete slabs and walls of very open timber construction. Attention paid to design problems associated with local methods of construction can often achieve dramatic improvements in earthquake resistance. When the destruction caused by a number of severe earthquakes is examined it is found that in many cases a few inexpensive design changes would have greatly reduced the damage and casualties.

Trends in construction

In the past, most European-style construction, particularly larger buildings and engineering works, has been confined to the less seismic Papuan areas. However, many major projects have now been started or are being planned for highly seismic areas. Schemes for hydro-electric stations, wharves, and bridges, are being examined. Hospitals, schools, office buildings, and European-style dwellings are being constructed. Native dwellings employing "permanent materials" are being introduced. Some of the latter failed disastrously in the Kokopo earthquakes of August 1967.

Nature of earthquake attack

An earthquake directs a two-pronged attack against structures. Inertial forces are applied directly to the structure by the accelerations of the supporting ground. Inertial attacks are particularly severe on heavy, low-strength buildings, for example, those of unreinforced masonry. The description of the inertial attack which is most suited to structural design is the Biot-Housner acceleration spectrum, and the derived velocity spectrum. These are normally calculated from recorded ground acceleration by digital computer.

The second method of earthquake attack is by ground damage. The ground supporting a structure may slump or fissure. Surrounding ground may slump and crush a structure. The ground may lose strength under earthquake vibrations and in extreme cases saturated alluvial deposits may liquefy. This ground damage attacks buildings by differential settlement and may lead to overturning. Very long structures are the ones most severely attacked by ground damage. These structures include bridges, buried or surface pipelines, power distribution networks, roads, and railways.

The local inertial attack depends on the softness and depth of the surface layers. The ground damage depends on the inertial attack and on the mechanical strength and steepness of the ground. Hence the inertial attack occupies a central position in all forms of earthquake attack. However, when the ground is particularly weak, is prone to collapse, or is excessively steep in relation to its strength, then the dominating factor in an earthquake attack will be ground strength.

The local variations in inertial attack may be estimated from the character of the surface layers. The surface layer profiles are difficult to measure and hence such estimates should be checked where possible by measurements of local changes in the ground acceleration.

In summary, the central factor in the attack of earthquakes on structures is the inertial forces associated with ground acceleration. The inertial attack is best described by the Biot-Housner acceleration spectrum calculated from recorded ground accelerations. Also an attempt should be made to estimate the ground damage to be expected from these inertial forces.

Design procedures

A code for the design and fabrication of earthquake-resistant structures which has been formulated for use in one seismic area cannot be easily adapted for use in another seismic area. Design difficulties arise from the peculiarities of local building styles, which are usually most marked for dwellings and for places of public assembly.

The simple code requirements for domestic buildings make many assumptions about types of construction, materials, and detailing, which will often not apply in another area. It is difficult to ensure that an equivalent earthquake resistance is provided by other materials and methods of construction. The difficulty arises because designs and comparisons are based upon simple static loads. However, the earthquake inertial attack can be described roughly as a series of jerks which apply very severe overloads. These transient overloads are best resisted by structures which exhibit toughness and endurance. As an example, a wood-sheathed timber-frame dwelling has such resistance. However, in the Territory such dwellings are frequently supported on slender steel tubes about eight feet high, with lateral resistance provided by diagonal rods anchored by a thread and nut. When a severe earthquake impulse is applied to the supported dwelling, these rods will suffer a brittle tensile failure at the thread root. This failure will occur even if the bars are capable of resisting normal seismic design loads. All such details which lead to a brittle mode of failure must be designed for much higher loads than the tougher parts of the structure.

Developing areas must base their earthquake resistant design on methods used in more developed areas. However, because of the difficulties arising from local material and building styles, expert opinion should be sought, particularly with regard to the more unusual styles of construction.

Tour of the Territory

A general picture of the earthquake engineering problems in the Territory of Papua & New Guinea was gained during a comprehensive tour from 13 to 26 August 1967, as given in the timetable in Appendix 1. The timetable was modified slightly to allow time for a rapid inspection ($1\frac{1}{2}$ days) of the earthquake damage in the Kokopo area of the Gazelle Peninsula. A preliminary report based on the inspection has been made by Skinner and Denham (BMR Record No. 1967/112).

Installation of accelerographs

Suitable sites were selected for two accelerographs for the Upper Ramu dam site. Two MO2 accelerographs were installed near Kieta, Bougainville, for Conzinc Rio Tinto of Australia Ltd. The methods of installation and maintenance were demonstrated to Dr Denham and to Mr John Dunkley, a technical officer employed by C.R.A. The demonstration MO2 accelerograph was shown to Mr Ian Brooks and to some members of the staff at BMR's Port Moresby Geophysical Observatory.

Discussions

Group discussions were held concerning the Upper Ramu project, and discussions were also held with the Structural Design Section of the Commonwealth Department of Works, the Electricity Commission, and "The Advisory Committee on Seismology and Earthquake Engineering (T.P.N.G.)". These discussions covered the contribution of strong-motion acceleration records to earthquake-resistant design. Also covered were general principles of earthquake-resistant design and some more-detailed group discussions, with groups, of those items which particularly concerned them.

Factors influencing engineering seismology programme

The group discussions, many informal discussions, and the extensive tour of the Territory provided a necessary and valuable background to enable recommendations and suggestions to be made with regard to earthquake hazards in this area. In particular a good picture was obtained of the present size and scope of the economy of the Territory and some indication of the likely lines of development. It was possible to see the present methods and scale of construction and form an impression of future trends. The inspection of earthquake damage gave valuable additional information on those types of construction which were present in the epicentral region.

Some of the recommendations arising from this work are included in section 3 of the report on the Kokopo earthquake. Particular points are expanded below.

3. RECOMMENDATIONS

Installation of two accelerographs at the Upper Ramu project

Two M02 accelerographs should be installed at the two sites selected in the area of the Upper Ramu project :

(a) Near the site chosen for the reservoir dam, a little above crest height and a little down stream from the eastern abutment of the dam.

(b) A site on steeply sloping rock a little down stream from the water meter station and at about the same elevation. The accelerograph on this site requires special protection against earth slides.

One accelerograph for the Palm Oil Project

The Palm Oil Project, Hoskins, should be encouraged to purchase an accelerograph for installation at the site of its oil extraction plant.

Introduction of strong-motion earthquake recorders

A single strong-motion acceleration recorder should be installed centrally in each of the following towns:

Rabaul
Lae
Port Moresby
Goroka
Mount Hagen
Madang
Wewak

In addition three accelerographs should be installed on substantial rock at well separated points; if possible these points should be reasonably near the sites of instruments located near town centres.

These three rock-based instruments, together with those on rock at Kieta, Bougainville, and at the Upper Ramu project site, will form a network of five recorders whose records should be related in a relatively simple manner to the earthquake magnitudes and epicentral positions recorded by the seismological observatories. The recorders at the major centres of construction will then show how the earthquake attack is modified by local ground conditions. This double network of accelerographs will give the maximum engineering significance to past and future seismological records.

These instrument installations could be spread over two to three years.

Creation of a post in earthquake engineering research

A post should be created for an officer who is primarily responsible for the collection of data related to earthquake-resistant design. He should ensure that these data are processed and reduced to forms suitable for use by structural design engineers.

It should be noted that earthquake engineering is outside the primary interest of seismologists. A special earthquake engineering post or group has therefore been established in many of those countries subject to earthquake damage. Earthquake engineering research would prosper best in an organisation devoted to research and development. However, strong ties should be established with the engineering design offices of the Commonwealth Department of Works and with design offices of the TPNG Administration.

A worker in this field will find that the proceedings of the first, second, and third world conferences on earthquake engineering provide an excellent general coverage of the subject (see Appendix 2). The references cited in the papers published in the above proceedings give a more detailed coverage of the literature. The authors of papers and other conference delegates include most of those active in the field. Furthermore, the addresses of these delegates delineate the areas and institutions actively engaged in earthquake engineering research and development.

Attention is drawn to the two International Schools of Earthquake Engineering conducted in Tokyo, Japan, and in Skopje, Yugoslavia, under the auspicies of UNESCO. If the officer chosen for the above post is not already an expert in earthquake engineering, his value would be greatly enhanced by a course at one of these two schools.

<u>Introduction of appropriate building code</u>

A large number of inadequate buildings can be avoided only by the introduction of codes for earthquake-resistant design. Some of the difficulties in adapting codes from other areas are discussed above.

Expert advice should be sought when developing the code. If possible a world expert should be retained for at least six months to study the earthquake engineering problems of the Territory and to draw up detailed code proposals for consideration by a suitable local committee.

UNESCO is now making substantial contributions towards earthquake engineering in developing countries. They could be approached with a request for advice in selecting a suitable world expert and for assistance in paying his fees. There are obvious advantages in choosing an expert from a country in which general building code provisions are similar to those in force in Australia.

Such an investment in the development of earthquake engineering would yield a quick return to the international community because of the very high seismicity of much of Papua & New Guinea. Advances in earthquake engineering will be greatly accelerated if most areas of high seismicity adopt modern principles and techniques in the design of earthquake resistant structures.

When a code is adopted, the provisions controlling domestic and other small buildings should be detailed and firmly endorced. Provisions for major structures may be a little more flexible. Special attention should be given to the correct use of building materials and to design principles. Domestic and other small buildings in the Territory offer particular difficulties. They differ in many crucial respects from corresponding buildings in other seismic areas. They are usually more restricted to local materials than are major structures, and these local materials, such as pumice concrete, may not have been adequately tested for mechanical properties. Furthermore, the designers of these small buildings are normally less sophisticated technically, and have more limited resources, than the designers of major structures.

Examination of earthquake damage

Steps should be taken to ensure that damage of future severe earthquakes has rapid and systematic engineering assessment.

Earthquake insurance

The possibility of introducing some form of earthquake damage insurance should be considered. The New Zealand Earthquake and War Damages Insurance could be examined in this regard. A by-product of insurance claim assessment is an accurate knowledge of the extent and type of damage. Engineering studies are still required to assess mechanisms of damage, however.

The above measures should greatly increase the efficiency and economy of earthquake-resistant design.

APPENDIX 1

THE AUTHOR'S ITINERARY - AUGUST 1967

Wednesday,	9 August	Sydney to Canberra
Saturday,	12 August	Canberra to Sydney
Sunday,	13 August	Sydney to Port Moresby
Monday, Tuesday,	14 August) 15 August)	Port Moresby - Discussions with Commonwealth Dept of Works. Inspection visit to Rouna No. 2 Hydro-electric Scheme.
Wednesday,	16 August	Port Moresby to Lae - Commonwealth Dept car from airport to Upper Ramu site. Inspected Ramu site and drove to Goroka.
Thursday,	17 August	Goroka to Madang - Investigation of site from airport tower and from harbour, in Administration transport.
		Madang to Rabaul via Wewak.
Friday,	18 August	Rabaul - Inspection of damage caused by Kokopo earthquake of 14 August 1967.
Saturday,	19 August	Rabaul to Bougainville - Directed installation of two accelerographs.
Sunday,	20 August	Bougainville to Rabaul - Further inspection of Kokopo earthquake damage.
Monday,	21 August	Rabaul - Visited the Geophysical Observatory.
Tuesday,	22 August	Rabaul to Hoskins - Drove from Hoskins and visited the Palm Oil Project, then crossed the Vagi River and went on to Talasea.
Wednesday,	23 August	Talasea to Lae - Inspected Higher Technical site and then returned to Port Moresby.
Thursday Friday,	24 August) 25 August)	Discussions in Port Moresby.
Saturday,	26 August	Port Moresby to Sydney Sydney to Canberra.
Tuesday,	29 August	Canberra to Sydney.

Dr. D. Denham accompanied the author throughout the tour of the Territory. The author was also accompanied by Mr A.J. Wight, an officer from the Commonwealth Department of Works, for most of the tour, and by Mr. J. Read, an Engineering Geologist, for part of it.

APPENDIX 2

KEY REFERENCES FOR EARTHQUAKE ENGINEERING RESEARCH AND DEVELOPMENT

1. Proceedings of the Symposium on Earth and Blast Effects on Structures. Los Angeles, California, June 1952.

Copies available from:

Secretary, Earthquake Engineering Research Institute,

465 California Street, San Francisco-4, California.

2. Proceedings of the World Conference on Earth Engineering.

Berkeley, California, June 1956

Copies available from:

Secretary, Earthquake Engineering Research Institute,

465 California Street, San Francisco-4, California.

3. Proceedings of 2nd World Conference on Earthquake Engineering.

Tokyo and Kyoto, Japan, 1960.

Published by: Gakujutsu Bunken Fukyo-kai.

(Assoc. for Science Documents information)

Oh-okayama, Meguro-ku, Tokyo.

4. Proceedings of 3rd World Conference on Earthquake Engineering.

Auckland and Wellington, New Zealand, January 1965.

Published by: R.E. Owen, Government Printer, Wellington. New Zealand 1966.

5. Design of Multistorey Reinforced Concrete Buildings for Earthquake Motions.

J.A. Blume, N.M. Newmark, L.H. Corning.

Published by : Portland Cement Assoc. Illinois, 1961.

6. A book on the design of earthquake resistant buildings to be published shortly by Professor J. Penzien of
University of California, Berkeley, California.

7. Earthquake Resistant Regulations: A World List, 1963.
Compiled by International Association for Earthquake Engineering.
Published by: Gakujutsu Bunken Fukyu-kai,
(Association for Science Documents information)
Oh-okayama, Meguro-ku, Tokyo, Japan.

APPENDIX 3

PRINCIPLES OF EARTHQUAKE-RESISTANT DESIGN

It is seldom economically practicable to design buildings and other structures, particularly large structures, to withstand the full forces of severe earthquakes within the elastic range of structural members. Materials and design details are chosen to give toughness (strain reserve) and endurance under very brief overloads.

A measure of toughness is the distance which the centre of gravity of the structure can deform horizontally beyond the limit of elastic deformation without losing lateral strength. Permissible overstrains of three to six times provide a large reserve of earthquake resistance.

A measure of endurance is the number of cycles of severe overstrain which a structure can withstand. A building has considerable endurance if it can withstand ten or more cycles of severe overstrain.

Steel frame structures have toughness if the beam and column connexions are over-designed, usually with the aid of haunches, so that beams and/or columns form plastic hinges near their ends under horizontal overloads. Where possible, beam and column ends should be constrained so that plastic hinges form at both ends. These beams and columns should not be excessively slender. Steel frames constructed in this way have a large endurance.

Reinforced concrete frames must have adequate steel bars placed to give moment resistant beam-column connexions. Adequate stirruping should be provided through junctions to contain compression concrete within the perimeter surrounded by longitudinal steel. Steel bar laps and particularly steel bar hooks should be avoided at the high moment regions near inter-connexions.

The above two forms of construction are relatively flexible and may be designed to withstand, within their elastic range, static horizontal forces of 0.1 to 0.2 times the building weight. The deformations during severe earthquakes will be at least four times the static design deformations, and difficulties may be experienced in protecting glazing and non-structural panels.

Comparatively rigid structures are obtained if diagonal bracing or infill block panels are used. This particularly applies to structures of not more than four storeys. Such rigid storeys should be designed for higher horizontal loads. Diagonal bracing by slender members is particularly prone to 'brittle' failure. The large elastic strength available from a small amount of diagonal bracing material may still justify their use in particular situations.

Structures and their foundations should be designed to act as a unit in resisting earthquake forces. Particular attention should be paid to the relative rigidity of components and to the balance of structures. 'L' and 'T' shaped structures should be avoided where possible by separation joints which form rectangular buildings which may move independently. It should be realised that earthquake displacements are four or more times as great as the elastic design displacements.

Adequate foundations call for examination of soil bearing capacity, quality control of concrete, and adequate reinforcing steel correctly placed.