RESEARCH REQUIREMENTS RELATED TO THE DESIGN OF SEISMIC RESISTANT HIGHWAY BRIDGES

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The recent article by D. Hutchison (Volume 15, No. 2) raising some questions regarding the problems and needs in earthquake engineering for structures is timely and should create much discussion. Engineers involved in the design of bridges have been aware of the need to look critically at their research activities and review the direction needed for future efforts. During the visit of a group of sixteen American bridge designers and researchers in December 1981, the opportunity was taken to undertake this review in a semi-formal three day workshop held in Wairakei.

Background

In 1979 the Applied Technology Council (ATC) of the USA held a workshop in San Diego on the design of earthquake resistant highway bridges to which selected overseas designers, including three New Zealanders, were invited. One of the prime objectives identified at that workshop was the fostering of cooperative research programmes with countries which have similar problems. Following this workshop it was proposed that a group of bridge designers and researchers would visit New Zealand with the aim of reviewing New Zealand activities in seismic design of bridges and associated research and to discuss future research in these areas.

The visit was arranged to take place in December 1981. Details were resolved through Dr Ron Mayes, then Executive Director of the ATC, and coordination and arrangements for the visit were executed by the Road Research Unit's (RRU) Structures Committee. (The Structures Committee is responsible to the RRU for research activities related to road structures (bridges, culverts, slopes and earthfills) undertaken on behalf of the National Roads Board.) The itinerary arranged for the visit involved informal discussions and visits in Auckland, Wellington and Christchurch during the first week followed by a three day workshop in Wairakei.

Wairakei Workshop

The objectives of this workshop were threefold:

- (i) to review the current position of seismic design of bridges and associated research in New Zealand and the USA;
- (ii) to determine what problems require attention in the future;
- (iii) to establish a framework for cooperative research.

To achieve these objectives the structure of the workshop was arranged so that brief papers were presented to inform

participants of the current situation in the two countries in nine general topics.

- design philosophy
- ground motions and design loading
- ductility
- base isolators and energy dissipators
- retaining structures and bridge abutments
- foundations
- design details and small bridges
- dynamic analysis and field testing
- strengthening/retrofitting

These brief presentations were followed by an extensive and free ranging discussion in which most of the research needs were identified. Research needs were discussed in depth on the final day of the workshop when the participants broke into five groups each of which had the opportunity to expand, contract or redirect research topics as it considered appropriate. The research topics listed later are in the same basic form as resolved by the discussion groups.

Aspects of cooperative research were discussed by Professor Alec Kibblewhite, the Executive Agent for the USA-NZ Cooperative Science Programme, based at Auckland University. His principal message was that cooperative research was dependent on the initiative of the individuals involved and contacts could be established through the ATC and the Structures Committee in the first instance.

The proceedings of the Waitakei Workshop are at present being printed as a RRU occasional Paper and will be available for those interested from the Secretary, RRU (PO Box 12041, Wellington).

Research Topics

The research topics presented below represent the opinions of the many leading bridge designers and researchers in the USA and New Zealand who gathered at the Wairakei Workshop. As such they must be considered to represent a reasonably definitive assessment as to the direction for future research. The list of topics is considerable, and it was difficult to gauge at the Workshop just where the priorities lay. To assist in defining where efforts are most urgently required a postal survey has been made, by the ATC, of the participants requesting them to rate the various projects from 0 to 10

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as they see the priorities. Unfortunately the results of this survey are not yet available and they will be published in the Bulletin later.

RESEARCH RECOMMENDATIONS:

I Strong-Motion Instrumentation and Studies -

(a) Ground-Motion

1. ANALYZE DATA FROM EXISTING FREE-FIELD ARRAYS TO ASSESS THE EFFECT OF SOURCE CHARACTERISTICS, ATTENUATION, PROPGATION PATH, AND LOCAL SITE CONDITIONS. IN AREAS OF HIGH SEISMIC ACTIVITY NOT YET INSTRUMENTED, INSTALL APPROPRIATE STATE-OF-THE-ART ARRAYS TO OBTAIN NEEDED ADDITIONAL INFORMATION.

The variation of strong-motion data parallel and perpendicular to the causative fault and the effect of local geology are of particular interest.

2. INVESTIGATE THE INFLUENCE OF SITE CONDITIONS, ATTENUATION, FAULTING MECHANISM AND DEPTH, AND SURFACE WAVES ON THE SHAPE AND AMPLITUDE OF GROUND-MOTION SPECTRA.

Design ground motions are frequently inferred from ground motion response spectra. The influence of the parameters mentioned required further study.

3. DEVELOP INSTRUMENTATION TO RECORD GROUND ROTATION; INSTALL IN AREAS OF HIGH SEISMIC ACTIVITY.

The effect of ground rotation due to surface wave ground motions on longer span bridges with tall columns can be significant. The magnitude of this effect is not yet understood.

4. INVESTIGATE OUT-OF-PHASE DISPLACEMENTS OVER DISTANCES COMPARABLE TO LENGTHS OF LONG BRIDGES; IN AREAS OF HIGH SEISMICITY, INSTALL STRONG-MOTION INSTRUMENTS ON IMPORTANT TYPES OF BRIDGES TO RECORD RELATIVE DISPLACEMENTS BETWEEN SUPPORTS.

Out-of-phase displacements of column and pier foundations may cause significant forces and/or displacements in structural components. The magnitude of this effect is not well understood.

5. DEVELOP ABSOLUTE-DISPLACEMENT MEASURING DEVICES TO RECORD GROUND MOTION AND STRUCTURAL RESPONSE. SUCH SYSTEMS SHOULD BE INSTALLED (1) TO RECORD LONG-PERIOD GROUND TRANSLATIONS AND ROTATIONS; (2) TO PROVIDE A CHECK ON DISPLACEMENT DETERMINED THROUGH THE DOUBLE INTEGRATION OF ACCELERATION RECORDS; AND (3) TO ENSURE ADEQUATE PROVISIONS FOR THE MOVEMENTS BETWEEN BASE AND SUPERSTRUCTURE IN BRIDGES WITH BASE-ISOLATED SUPERSTRUCTURES.

Displacements are an important design parameter and are not well documented. The information described above will provide a better understanding of

absolute displacements.

(b) Structural Response -

1. INVESTIGATE VERTICAL MOTIONS TO DETERMINE THEIR EFFECT ON DIFFERENT TYPES OF STRUCTURES, PARTICULARLY LONG-SPAN STRUCTURES.

Vertical seismic ground motions are not explicitly considered in current design. Their effect may be important in long span bridges and should be investigated.

2. INVESTIGATE THE EFFECT OF LONG-PERIOD (APPROXIMATELY 1 SECOND AND LONGER) GROUND-MOTION PULSES ON INELASTIC STRUCTURAL BEHAVIOUR.

Long period pulses have recently been determined to be a characteristic of ground motions close to some causative faults. The impact on the inelastic response of structures can be severe and requires further study.

3. STUDY CURRENT TECHNIQUES FOR INSTRUMENTING BRIDGES WITH ACCELERATION-RECORDING INSTRUMENTATION; DEVELOP APPROPRIATE NEW INSTRUMENTATION; IN APPROPRIATE AREAS OF HIGH SEISMICITY, INSTALL SUCH INSTRUMENTATION ON IMPORTANT TYPES OF BRIDGES NOT YET ADEQUATELY INSTRUMENTED.

II Design Loadings -

1. INVESTIGATE THE USE OF EQUAL DISPLACEMENT AND EQUAL ENERGY TECHNIQUES TO DEVELOP INELASTIC DESIGN SPECTRA; VERIFY VIA NONLINEAR TIME-HISTORY ANALYSES OF DIFFERENT STRUCTURES; ASSIGN CONFIDENCE LEVELS.

2. DEVELOP RISK CRITERIA TO ASSIST IN THE SELECTION OF DESIGN LOAD LEVELS FOR A RANGE OF RETURN PERIODS; INCLUDE COST BENEFIT STUDIES.

3. PRODUCE RECOMMENDATIONS ON DAMPING RATIOS.

4. EXAMINE THE POSSIBLE JUSTIFICATION FOR APPROPRIATELY LOWERING THE LEVELS OF SEISMIC DESIGN LOADING FOR SMALL BRIDGES WHERE STRUCTURAL RESTRAINT IS DOMINATED BY ABUTMENT EARTH PRESSURE. (SMALL BRIDGES ARE DEFINED AS THOSE HAVING A TOTAL LENGTH BETWEEN ABUTMENT RESTRAINTS NOT EXCEEDING 250 FEET).

Although this research recommendation is directed toward small bridges, it is intended that research results could also be applied to any bridge which has no separation at the abutments between the approach embankments and the bridge superstructure. In such cases, it is expected that dissipation provided by the approach fills would result in lower seismic loading to the bridge superstructure and its pier connections.

5. BASED ON A REVIEW OF CURRENT CRITERIA IN BOTH COUNTRIES, ESTABLISH ACCEPTABLE LEVELS OF SEISMIC LOADING

TO LIMIT STRUCTURAL DAMAGE IN CONFINED CONCRETE COLUMN SECTIONS.

This investigation should be designed to determine the level at which structural damage commences during expected earthquake ground motions and whether this level is compatible with the desired ductility.

III Ductility and Structural Performance Investigations -

1. ASSESS THE IMPORTANCE OF EARTHQUAKE DURATION AND INELASTIC RESPONSE DURATION ON DUCTILITY DEMANDS.

2. ASSESS THE INFLUENCE OF FOUNDATION AND BEARING FLEXIBILITIES ON DUCTILITY DEMANDS IN PIERS.

3. ASSESS THE ADVANTAGES OF ACCURATE ELASTIC ANALYSIS TO ENSURE UNIFORM HINGE DEVELOPMENT; INVESTIGATE THE EFFECTS OF NON-UNIFORM HINGE FORMATION THROUGH PARAMETRIC STUDIES.

4. PREPARE DESIGN CHARTS AND DESIGN PROCEDURES BASED ON RECENT RESEARCH INTO THE STRESS/STRAIN CHARACTERISTICS OF CONFINED CONCRETE; DEVELOP ASSOCIATED COMPUTER PROGRAMS.

Recent research at the University of Canterbury has shown that up to 7% strain is possible in well-confined concrete. Design charts should be updated to incorporate this new information and allow designers to readily calculate section curvature and structure ductility capability.

5. PRODUCE A UNIFIED PERFORMANCE CRITERION FOR DUCTILITY TESTS ON COMPONENTS.

6. INVESTIGATE THE PERFORMANCE OF BRIDGES WITH LONG LENGTHS BETWEEN CONTRACTION AND EXPANSION JOINTS.

7. INVESTIGATE THE ADVANTAGES OF FOUNDATION UPLIFT.

Most design codes will not permit foundation uplift. Foundation uplift may reduce design forces, especially in foundations, and increase resulting displacements; its effect requires further investigation.

8. INVESTIGATE THE EXTENT TO WHICH EXISTING RESULTS FROM TESTS ON DUCTILE BUILDING SHEAR-WALLS CAN BE USED TO EVALUATE THE DUCTILITY CHARACTERISTICS OF WALL-TYPE BRIDGE PIERS.

There are basic structural similarities between shear walls for buildings and wall-type bridge piers; the considerable amount of research conducted on the ductility of building shear walls may be appropriate for wall-type piers.

9. INVESTIGATE THE CONSEQUENCES OF THE VARIABILITY OF STEEL AND CONCRETE QUALITY ON THE PERFORMANCE OF CRITICAL BRIDGE COMPONENTS; DEVELOP METHODS FOR CONTROLLING THE VARIABILITY OF MATERIAL STRENGTHS IN MEMBERS ADJACENT TO YIELDING HINGES.

IV Component Testing and Evaluation -

1. INVESTIGATE THE EXTENT TO WHICH ALLOWANCE IN DESIGN FOR LARGE CONCRETE STRAINS IN A WELL-CONFINED CORE COULD LEAD TO SPALLING OF THE COVER CONCRETE AT LOADING CORRESPONDING TO RELATIVELY MODERATE EARTHQUAKE SHAKING.

2. IMPLEMENT A PROGRAM OF TESTING HOLLOW CIRCULAR CONCRETE PIERS.

In some cases, a savings in the cost of construction (due to the reduction in mass subject to seismic acceleration) can result from the use of hollow bridge piers. Tests have already been performed on hollow rectangular piers and this work needs to be extended to hollow circular piers to determine the manner in which the inside face of the pier needs to be confined by reinforcement.

3. CONDUCT TESTS ON COLUMN-TO-PILE-CAP AND PILE-TO-PILE-CAP CONNECTIONS FOR DIFFERENT PILE TYPES.

Further information is required on suitable detailing at pile-cap connections to ensure a correct failure hierarchy.

4. CONDUCT TESTS ON THE SHEAR STRENGTH OF CIRCULAR AND SQUARE REINFORCED-CONCRETE COLUMNS.

Tests on the shear strength of circular and square reinforced-concrete columns are required to determine the reduction of the concrete contribution to the shear strength during intense dynamic and cyclic loading.

5. CONDUCT EXPERIMENTAL WORK ON THE STRESS/STRAIN CHARACTERISTICS OF CONFINED CONCRETE, INCLUDING THE EFFECTS OF DIFFERENT GRADES OF STEEL.

Continued testing on the stress/strain characteristics of confined concrete is required to further assess the effects of shear force, compression loading, and other variables on the behaviour of confined concrete. With regard to grades of steel, it is important to bear in mind that New Zealand tests have been conducted with 40-grade steel, whereas the use of 60-grade steel is widespread throughout the United States.

6. INVESTIGATE THE EFFECTS OF DIAGONALLY-ACTING SEISMIC FORCES ON SQUARE OR RECTANGULAR PIERS, I.E. ACCELERATIONS CAUSING BIAXIAL BENDING.

The New Zealand Concrete Design Code recommendations for confining reinforcement have been determined for solid

piers of circular or square cross-sectional shape. Further tests are required to check the reinforcement requirements for seismic forces acting along diagonal planes of square or rectangular piers, and perhaps other cross-sectional pier shapes.

7. CONDUCT PERFORMANCE TESTING OF REINFORCED-CONCRETE COLUMN SECTIONS SUBJECTED TO COMBINED TENSILE/FLEXURAL LOADING.

Such tests are important for tall multi-column piers or pile bents.

8. INVESTIGATE THE DEFORMATION AND PERFORMANCE OF CORNER KNEE JOINTS OF RIGID FRAME TYPE BRIDGES.

This recommendation is intended to apply to such structures as multi-cell culverts where plastic hinging can occur close to the corner regions.

9. ENCOURAGE AGENCIES THAT HAVE CONDUCTED TESTING WORK ON BRIDGE COMPONENTS TO SHARE RESEARCH DATA, I.E. TO PROVIDE FOR THE INTERCHANGE OF RESEARCH DATA, INCLUDING THE SHARING OF ACCESS TO DATA BASES OF TESTING RESULTS.

The bridge components visualised include "knock-off" slabs and hinged slabs, linkage and hold-down bolt details, shear keys, elastomeric bearing connection details and any other similar components subjected to full scale testing.

V Base Isolation And Energy Dissipating Devices -

1. CONTINUE DEVELOPMENT OF ENERGY DISSIPATING DEVICES; IMPROVE THE PERFORMANCE OF LEAD-RUBBER DEVICES AT LOW COMPRESSION LOADS AND INVESTIGATE METHODS OF ANCHORING THEM TO PREVENT SLIP AT HIGH SHEAR STRAINS; PURSUE DEVELOPMENT OF OMNI AND UNI-DIRECTIONAL DEVICES USING HYSTERETIC MATERIALS OR DUCTILE ELEMENTS.

2. CONDUCT THE FOLLOWING SHAKE-TABLE TESTS TO STUDY STRUCTURE-DISSIPATOR INTERACTION:

- (a) Full scale dynamic tests of lead-rubber dissipators supporting realistic dead loads provided by a concrete slab.
- (b) Dynamic tests of model structures such as regular curved or skewed bridges supported on model dissipators.
- (c) Comparison of experimental response with theoretical computer predictions.

3. CONDUCT FORCED-VIBRATION TESTS ON FULL-SCALE BRIDGES SUPPORTED ON BASE ISOLATORS AND/OR ENERGY DISSIPATORS; INVESTIGATE DECK AND PIER RESPONSE TO LEVEL OF LOADING THAT FORCES DISSIPATORS TO YIELD; COMPARE EXPERIMENTAL RESPONSE WITH ANALYTICALLY-DETERMINED RESPONSE.

4. CONTINUE DEVELOPMENT OF DESIGN CHARTS; GENERALIZE TO INCLUDE SPECTRAL BEHAVIOUR OF SINGLE-DEGREE-OF-FREEDOM OSCILLATORS; INVESTIGATE THE APPLICATION OF DESIGN AIDS FOR COMPLEX BRIDGE STRUCTURES SUCH AS CURVED, MULTI-MODE AND BRIDGES ON ROCKING FOUNDATIONS.

5. DEVELOP STATE-OF-THE-ART SEISMIC DESIGN GUIDELINES FOR BASE-ISOLATED STRUCTURES WITH ENERGY DISSIPATORS.

Design guidelines for base-isolated structures are currently incorporated in code-form in NZS3101:1982 (published in April 1982) and are discussed elsewhere in existing literature, including the Bulletin of the New Zealand National Society for Earthquake Engineering, vol. 12, no. 2 (June 1979).

VI Abutments and Foundations -

(a) Abutment Walls

1. INVESTIGATE INTERACTIVE SOIL-WALL PRESSURES UNDER EARTHQUAKE LOADING BY MEANS OF SHAKE-TABLE OR FIELD TESTS, ANALYTICAL METHODS AND FIELD INSTRUMENTATION.

Research effort should be conducted preferably by a team comprised of a structural analyst, a geotechnical engineer and a bridge designer.

2. PERFORM RESEARCH ON WALLS DESIGNED TO DISPLACE IN EARTHQUAKES WITH THE AIM OF EXTENDING THE ANALYTICAL MODELS CURRENTLY IN USE TO PROVIDE DESIGN GUIDELINES FOR SUCH SYSTEMS.

3. PERFORM FUNDAMENTAL RESEARCH, INCLUDING SHAKE-TABLE TESTS, ON ALL TYPES OF TIED WALLS, INCLUDING REINFORCED EARTH AND THOSE ANCHORED TO FRICTION SLABS.

Research effort should be conducted preferably by a team comprised of a structural analyst, a geotechnical engineer and a bridge designer.

(b) Approach Embankments

1. DEVELOP DESIGN CRITERIA TO MINIMIZE SETTLEMENT AND PROVIDE STABILITY OF APPROACH EMBANKMENTS (AND ABUTMENTS) UNDER SEISMIC LOADING.

(c) Piled Foundations

1. PERFORM FUNDAMENTAL RESEARCH ON THE DYNAMIC BEHAVIOUR OF PILE FOUNDATION SYSTEMS, INCLUDING PILE GROUP EFFECTS.

Investigations should include both cohesive and noncohesive soils as well as pile installation effects. Reliable methods of estimating the end bearing capacity of large diameter piers also need to be developed. Research effort should be conducted preferably by a team comprised of a structural analyst, a geotechnical engineer and a bridge designer.

2. DEVELOP INVESTIGATION APPARATUS TO DETERMINE INSITU LATERAL SOIL

FORCE-DEFORMATION RELATIONSHIPS FOR PILES.

Aspects of this research should include an investigation of the effect of pile diameter on the pile force/deformation relationship and also the effects of pile installation. The use of existing pressure-meter lateral force/deflection relationships for piles should be investigated.

3. CONDUCT PARALLEL STUDIES TO RELATE LABORATORY TESTS (INCLUDING CENTRIFUGE MODELS), FULL SCALE FIELD TESTS, AND ANALYTICAL METHODS TO THE DEVELOPMENT OF SUBGRADE REACTION DATA UNDER STATIC, CYCLIC AND DYNAMIC CONDITIONS.

Research effort should be conducted preferably by a team comprised of a structural analyst, a geotechnical engineer and a bridge designer. Field tests should include pile groups.

4. INVESTIGATE THE USE OF RAKED PILES TO RESOLVE QUESTIONS OF SUITABILITY; PRODUCE GUIDELINES FOR THE DESIGNER.

5. DEVELOP A RATIONAL PROCEDURE TO DETERMINE THE DAMPING EXHIBITED BY TYPICAL BRIDGE STRUCTURES UNDER EARTHQUAKE CONDITIONS AND IN PARTICULAR THE PROPORTION DERIVED FROM RADIATION AND INELASTIC EFFECTS IN DIFFERENT SOILS.

5% equivalent viscous damping is presently assumed.

(d) Critical Reviews of the Literature

1. In the following subject areas, it would be of considerable value for a critical review to be made of the available literature, and to summarise the state-of-the-art in concise form useful to the designer.

(a) Full scale tests of lateral loading of piles and subgrade reaction correlations;

(b) Foundation investigation methods;

(c) Liquefaction of soils.

VII Retrofit Investigations -

1. DEVELOP SUITABLE REPLACEMENT DETAILS FOR NORMAL BEARINGS, ROCKERS, AND ROLLERS THAT WILL, WHERE POSSIBLE, FIT INTO THE ORIGINAL SPACE PROVIDED AND WILL PROVIDE ACCEPTABLE SEISMIC PERFORMANCE.

2. DETERMINE SEATING WIDTHS AND CLEARANCES REQUIRED FOR ABUTMENT AND PIER-CAP SEATINGS.

3. CONDUCT A CRITICAL RE-EXAMINATION OF THE FUNCTION AND DESIGN OF LINKS AND RESTRAINERS FOR BOTH STEEL AND CONCRETE SUPERSTRUCTURE ELEMENTS; DEVELOP SYSTEMS TO SMOOTH THE PERFORMANCE OF LINKAGE TIES TO REDUCE THE IMPACT EFFECTS IF THEY PROVE TO

BE DETRIMENTAL IN THE PERFORMANCE OF THE STRUCTURE; DETERMINE IF HOLD-DOWN BOLTS ARE NECESSARY; DEVELOP NEW TYPES OF LINKAGES, E.G., GLU-ON PLATES, BOLT PLATES.

It may be desirable to eliminate gaps within super structures to provide a smooth transition in stiffness from very low values at normal service to high values when significant earthquake motions occur.

4. INVESTIGATE THE POSSIBLE ADVANTAGES TO BE GAINED BY THE DELIBERATE INTRODUCTION OF WEAKENED PLANES OF PLASTIC HINGES INTO EXISTING STRUCTURES; DEVELOP PRACTICAL DETAILS TO IMPLEMENT THIS CONCEPT.

It is critical that inertial forces be positively controlled in order to ensure that they are effectively carried to the foundation. The use of various materials such as epoxy resins, steel sheathing, and fibra-reinforced concrete should be investigated.

5. DEVELOP DUCTILE SYSTEMS TO REPLACE STEEL COMPRESSION BUCKLING TYPE STEEL BRACES.

6. INVESTIGATE THE STABILITY OF STEEL MEMBERS IN THE INELASTIC RANGE.

7. DEVELOP METHODS AND RETROFIT DETAILS FOR STEEL PIER SHAFTS TO ENSURE GREATER POST BUCKLING STRENGTH AT PLASTIC HINGE LOCATIONS.

Greater rotation and displacement ductility factors are desirable.

8. DEVELOP BETTER METHODS AND INSTRUMENTS TO PERMIT ASSESSMENT OF THE EXISTING STRENGTH OF STRUCTURES TO BE RETROFITTED; DEVELOP METHODS TO DETERMINE THE SIZE, LOCATION, AND AMOUNT OF REINFORCING IN A SECTION.

Methods and instruments for underground elements such as piles are especially important.

9. EVALUATE THE USE OF GROUTING, EARTH REINFORCEMENT, AND OTHER TECHNIQUES TO IMPROVE THE SEISMIC PERFORMANCE OF EXISTING FOUNDATIONS.

10. ESTABLISH A DATA BANK OF RETROFIT CASE HISTORIES.

This data set should include information on any tests performed on the retrofitted structure as well as the cost of the work.

VIII Full-Scale Testing

1. CONDUCT FULL-SCALE NON-DESTRUCTIVE DYNAMIC TESTS ON BOTH EXISTING AND RETROFITTED STRUCTURES TO OBTAIN MORE REALISTIC VALUES OF DYNAMIC PROPERTIES.

All types of standard structures should be tested; this effort should encompass ambient-vibration, snap-back, and forced-vibration testing. Non-

destructive testing of instrumented bridges is particularly important as such tests would provide data useful in interpretation of subsequently recorded strong-motion data.

2. CONDUCT FULL-SCALE DESTRUCTIVE TESTS ON ABANDONED OR SPECIALLY BUILT TEST STRUCTURES.

Dynamic loading should cover the full range from ambient to destructive.

3. PERFORM LARGE-AMPLITUDE NON-DESTRUCTIVE TESTS ON VARIOUS COMPONENTS OF NEW BRIDGES UNDER CONSTRUCTION.

Data on lateral, vertical, and rotational foundation stiffness are particularly critical.

4. DETERMINE THE EFFECT OF OUT-OF-PHASE GROUND MOTIONS USING PARTIAL-SCALE MODELS OF BRIDGES.

5. INVESTIGATE THE DESIRABILITY OF USING EXPLOSION-GENERATED GROUND SHAKING TO FORCE VIBRATE STRUCTURES, RATHER THAN MECHANICAL SHAKERS.

6. PREPARE A REGISTER OF BRIDGES THAT ARE BECOMING REDUNDANT SO THAT SUITABLE ONES CAN BE SELECTED FOR DESTRUCTIVE TESTING.

7. PERFORM SHAKING TABLE TESTS TO INVESTIGATE PIER DUCTILITY AND TO EVALUATE ANALYTICAL TECHNIQUES FOR MODELLING PIERS.

Summary:

The extensive list of topics identified at the Wairakei Workshop indicates that there are many aspects related to the design of seismic resistant bridges which deserve attention to improve our understanding of the behaviour and performance of bridges. Many of these topics identified are common to many structural design problems, particularly in the areas of ground motions, design loadings, structural response, ductility, component testing, base isolation, retaining structures and foundations.

References:

- (i) Hutchison, D.L., "Buildings : Research and Development Needs", Bulletin of NZNSEE, Vol 15, No 2, June 1982, pp 92-95.
- (ii) "Proceedings of Workshop on Earthquake Resistance of Highway Bridges - San Diego", Applied Technology Council, November 1979.
- (iii) "Proceedings of a Workshop on the Design Seismic Resistant Highway Bridges - Wairakei", Road Research Unit Occasional Paper, December 1981.