3. THE PROCEDURE

3.1 Identification of the Bridges to be Totally Excluded from Screening

Bridges in the following categories shall be excluded from the assembly and inspection of drawings and from the seismic screening procedure:

- Structures designated as "Structure Type - Culvert" in the Transit New Zealand Bridge Descriptive Inventory;
- Bridges not managed by Transit New Zealand;
- Bridges designated by Transit New Zealand for replacement within five years from the date of the screening project, subject to review by the Regional Manager, Transit New Zealand. This review may eventuate from advice from the screening consultant that individual critical bridges may warrant some retrofitting, even though early replacement is planned; and
- Bridges designated at the discretion of the Regional Manager, Transit New Zealand.

The names and route position identifiers for these bridges shall be listed in the report in a summary list of all the bridges to which the report refers (Section 4.2).

3.2 Assembly and Recording of the Bridge Data (Part 1)

The forms in Appendix B, and those referred to in Appendix C, are to be used for recording the basic data about each applicable bridge on the highway system. The forms are written in Microsoft Word 97 or Excel 97 and are available on diskette.

Engineering personnel familiar with the bridges within each Transit New Zealand region should undertake the compilation and most of the seismic attributes grading work (Section 3.5) to ensure consistency within each region.

The basic data, which will normally be available by accessing existing databases, should include:

- Details of the bridge recorded on the bridge descriptive inventory;
- Bridge construction drawings; and
- Bridge inspection records.

If records are incomplete, the local knowledge of personnel should enable the work to be completed without a site visit. If the personnel are not sufficiently familiar with the structure they should visit the site to ensure that all relevant details are known and recorded. Information required from a site inspection is listed in Section 3.6.

The information on soil condition and risk of liquefaction effects requires input from a specialist geotechnical engineer. In most cases detailed site investigation information is not available, but it is expected that the best judgement possible will be made on the basis of geological maps, local knowledge etc.

The vulnerability of bridge approaches is not addressed by this ranking procedure. The potential hazard to vehicles if a bridge approach settles and exposes the abutment back wall is also not addressed. The presence or absence on bridge drawings of approach settlement slabs are to be noted on Form 1 when details of structures are extracted from the records, and are to be listed on the summary spreadsheet (Figure 6). A decision on whether slabs should be installed may then be appropriate as part of the retrofit decision at a later stage.

3.3 Identification of Those Bridges to be Partially Excluded from Screening, and Those with Spans not Interconnected

3.3.1 Partial Exclusion

Some bridges, although not qualifying for total exclusion, are clearly seismically robust and do not require screening or more detailed seismic analysis. Form 2 in Appendix B, entitled "Can bridge be excluded from further screening?", sets out the conditions required for a bridge to be excluded from further screening and ranking. The detailed records and drawings of the bridge must be assembled for perusal before the decision is made that the bridge is to be excluded.

Screening data for similar structures, such as twin bridges on a motorway, may be combined on the same set of forms, provided that their structural characteristics and predicted seismic performance are practically the same and that their individual identifiers are recorded on the forms.

3.3.2. Bridges that lack Connections between Superstructure Elements

It is likely that there are some bridges in which the spans are neither interlinked nor otherwise restrained against significant relative displacement via substantial holding down bolts, shear keys, web cleats or tie-bars into the piers. The rough order cost of providing connections between superstructure elements for these structures shall be determined and reported (Section 4.2).

To class as "substantial" the capacity of elements with little ductility, such as holding down bolts that restrain by shearing action, and their containing concrete, shall meet the following criterion: If the total ultimate shear capacity available to restrain a span is less than 0.6g times the mass of the span, the elements should be classed as inadequate *in terms of this clause*.

The lack of connection between segments of a bridge superstructure is one deficiency that is readily improved by retrofitting. The interconnection of bridge superstructure segments is usually inexpensive and has the advantage that it can also partially alleviate the seriousness of other deficiencies.

Bridges with either:

- simply supported spans supported on intermediate piers, or
- intermediate hinges within spans

that lack substantial direct or indirect connections between superstructure elements, shall be individually identified for the following reasons:

- The risk of span collapse in these bridges in a moderate earthquake can be relatively high;

- The total number of such bridges is small; and

- The benefit of increased security relative to the cost of retrofit is usually high.

The order of ranking shall be based on the annual average daily traffic count (AADT) of traffic using the bridge and on the seismic zone factor (Z) applicable to the bridge site, as defined in Appendix D:

1. Bridges with AADT exceeding 4000 v.p.d. or 400 heavy v.p.d., with a seismic zone factor (Z) ≥ 1.2

2. Bridges with AADT less than 4000 v.p.d. and less than 400 heavy v.p.d., with a seismic zone factor (Z) ≥ 1.2

3. Bridges with AADT exceeding 4000 v.p.d. or 400 heavy v.p.d., with a seismic zone factor (Z) < 1.2

4. Bridges with AADT less than 4000 v.p.d. and less than 400 heavy v.p.d., with a seismic zone factor (Z) < 1.2

This information shall be recorded on Form 3 in Appendix B. Bridges that lack connections between superstructure components shall be subjected to Stages 4 to 11 shown in Figure 1 (Sections 3.4 to 3.11). The ranking of the bridges relative to those for all other bridges in the group being screened will then be available for deciding the extent of retrofit work that might justifiably accompany the rectification of the linkage deficiency. The lack of connections between spans shall not influence the ranking of the bridges with respect to other deficiencies, since the lack of connections are to be rectified in any case.

3.4 Assembly and Recording of the Bridge Data (Part 2)

Stage 4 comprises assembly and recording of information that is only required for bridges that are not partially excluded in Stage 3. This relates to the length of detour and assessed journey speeds along it, facilities that are carried or crossed by the bridge, and other miscellaneous information. The detour information is to be obtained from maps, while the assessed journey speeds are to be estimated from local experience or judgement, taking account of the road alignment and potential bottlenecks.

3.5 Derivation of Provisional Seismic Attributes Grades (SAG)

3.5.1 The Seismic Attributes Grading System (SAGS)

The SAGS includes three main variables:

- Hazard (seismicity at the bridge site and other hazards that affect the bridge structure);

- Importance of the bridge; and

- Vulnerability of the bridge structure.

Figure 2 Attributes Grading Sheet

SEISMIC SCREENING OF BRIDGES: FORM 4 OF 5
SEISMIC ATTRIBUTES GRADING SYSTEM
GRADING SHEET

(Refer to Appendix A for derivation of Rating values)

BRIDGE AUTHORITY/REGION ....

HIGHWAY .... ROUTE POSITION ....

BRIDGE NAME ....

	Rating		Weighting		Weighted Rating
Hazard Index					
Peak Ground Acceleration Rating	....	x	0.40	=	....
Remaining Service Life Rating	....	x	0.30	=	....
Soil Condition Rating	....	x	0.15	=	....
Risk of Liquefaction Rating	....	x	0.15	=	....
	Total = Hazard Index				______
Importance Index					
AADT on Bridge Rating (............) x *Detour Effect* Rating (............)		x	0.50	=	....
AADT under Bridge Rating	....	x	0.10	=	....
Facility Crossed Rating	....	x	0.15	=	....
Strategic Importance Rating	....	x	0.15	=	....
Critical Utility Rating	....	x	0.10	=	....
	Total = Importance Index				______
Vulnerability Index					
Year Designed Rating	....	x	0.25	=	....
Superstructure Hinges Rating	....	x	0.08	=	....
Superstructure Overlap Rating	....	x	0.10	=	....
Superstructure Length Rating	....	x	0.12	=	....
Pier Type Rating	....	x	0.15	=	....
Skew Rating	....	x	0.05	=	....
Abutment Type Rating	....	x	0.10	=	....
Other Feature Rating	....	x	0.15	=	....
	Total = Vulnerability Index				______

Seismic Attributes Grade = Hazard Index x Importance Index x Vulnerability Index

= [ ]

Each *variable* is based on a number of *attributes*. Each attribute is assigned a relative weight based on the attribute's significance, and a rating value that depends on the characteristics of the individual structure. In the SAGS procedure each variable is assigned an *index*, which is the sum of the weighted attribute rating values for that variable. The indices are then combined to give the *Seismic Attributes Grade*. Figure 2 illustrates the general structure of the SAGS, and Table 1 contains a detailed summary.

3.5.2 Summary of the Seismic Attributes Grading System

Table 1 (following) summarises the Seismic Attributes Grading System. Details and forms for application of the system are contained in Appendices A to C.

DERIVING THE SEISMIC ATTRIBUTES GRADE (SAG):

• **Hazard**	**Hazard Index = sum of:**	
Peak ground acceleration	[Z/1.2]	x 0.4
Remaining service life	[>50 yrs 25yrs-50yrs <25yrs] 1.0 0.7 0.5	x 0.3
Soil condition	[flexible, deep or "don't know"] [intermediate] [Rock or very stiff] 1.0 0.5 0	x 0.15
Risk of liquefaction effect	[high risk or "don't know"] [moderate risk] [low (or no) risk] 1.0 0.5 0	x 0.15
• **Importance**	**Importance Index = sum of:**	
AADT count on bridge	[AADT/30,000) ≤ 1.0]) Product of) Rating	
Detour Effect	[extra distance travelled/100 ≤ 1.0]) Values	x 0.50
AADT count under bridge	[AADT/30,000 ≤ 1, but = 1 if over railway]	x 0.10
Facility crossed	[residential, operational, commercial, industrial: 1.0] [parking, storage: 0.5] [other uses or railway: 0]	x 0.15
Strategic Importance	[Motorway or Urban class or AADT > 10,000 v.p.d. or >600 Heavies: 1.0] [AADT 4,000-10,000 v.p.d. or 400-600 Heavies: 0.9] [AADT 1,000-4,000 v.p.d. or 200-400 Heavies: 0.7] [AADT <1,000 v.p.d., or Heavies < 200: 0.6]	x 0.15
Critical utility	[utility carried: 1.0]) in pipes with an [utility not carried: 0]) internal diameter > 100 mm	x 0.10

Table 1 (continued)

- **Vulnerability** — **Vulnerability Index = sum of:**

Year designed	[pre-1933] 1.0 / [1933-1972] 0.5 / [post-1972] 0	x 0.25
Superstructure hinges in spans	[2 or more] 1.0 / [1] 0.5 / [none] 0	x 0.08
Superstructure overlap on supports	[(no linkage or loose linkage: o'lap < 400): 1.0] o'lap ≥ 400): 0] [(HD bolts in shear: o'lap < 300): 1.0] o'lap ≥ 300): 0] [(tight tension linkage: o'lap < 200): 1.0] o'lap ≥ 200): 0]	x 0.10
Superstructure length	[>200m] 1.0 / [100-200m] 0.8 / [40-<100m] 0.6 / [20-<40m] 0.2 / [<20m] 0	x 0.12
Pier type	[single column: 1.0] [multi-column, or slab pier on piles: 0.5] [slab pier on spread footing: 0.25]	x 0.15
Skew	[skew angle/90] ≤ 1.0	x 0.05
Abutment type	[non-monolithic] 1.0 / [monolithic] 0	x 0.10
Other feature	[feature present] 1.0 / [not present] 0 (or intermediate value subject to judgement)	x 0.15

SAG = Hazard Index x Importance Index x Vulnerability Index

3.5.3 Use of the Seismic Attributes Grade

The seismic attributes grading system, summarised in Table 1, provides a seismic attributes grade (SAG) for each bridge. The SAG provides one indicator for ranking the bridges for subsequent detailed seismic assessments, with a lesser SAG value indicating a lower ranking.

It should be noted that pilot screening projects have shown that ranking of bridges using an indicator such as the SAG alone does not provide consistent results, but that even so the SAG is a useful indicator. The SAG, the risk assessment (Section 3.9), the economic ranking indicator (Section 3.10) and other indicators (Section 3.11.3.2) should be used to decide the ranking, and to decide those bridges that are most likely to give the best return on the cost of retrofitting.

3.6 Site Inspection

3.6.1 General

It is expected that local personnel will be sufficiently familiar with many of the bridges to enable them to confidently certify that the drawings correctly represent the existing structure. There will be bridges where this is not the case - for example where bearings, linkages or other modifications may have been added that would improve the seismic resistance, or where the available drawings do not fully describe all parts of the structure. It is important that before Stage 7 (Figure 1) the reliability of the recorded basic information on the bridge is established. If there is doubt then the bridge must be visited (Stage 6) in order to confirm the details of critical elements. The inspection should be planned so as to provide all outstanding required information in one visit.

In some cases the specialist review in Stage 7 (Figure 1) will result in queries about critical structural items that can only be clarified by a visit to the site. In such cases a site visit should be made before Stages 8 to 11 are undertaken.

3.6.2 Personnel

Site inspections will normally be undertaken by an experienced bridge inspector or a competent bridge designer. Depending on the type of structure to be visited it may be advisable to consult seismic specialists in the bridge and/or geotechnical engineering fields before the visit to identify critical areas of the structure that should be recorded.

It is not expected that critical details will be evaluated during the site visit, but rather that they will be identified, fully recorded and measured to facilitate subsequent evaluation.

3.6.3 Objectives of Visit

The objectives of a site visit are:

- To confirm that the drawings fully represent the existing bridge, including significant details;

- To obtain additional information when necessary;

- To identify any details of the structure that are potential seismic vulnerabilities; and

- To record the results of the visit on forms and with photographs.

3.6.4 Items to be Noted

Items to be noted during the site visit may include the following:

- Does the bridge possess any significant structural differences from the details shown on the drawings? For example :

- Have the foundations been modified by underpinning?
- Have the pilecaps been modified by adding extra concrete?
- Have the piers been modified with added concrete or steel, or have their effective lengths been altered?
- Has the bridge been widened?
- Have the bearings been altered or replaced?
- Are the overlaps of beams at their supports the same as shown on the drawings?
- Are linkages between superstructure elements as shown on the drawings?
- Is there any significant raising or lowering of the river bed level that could cause a change of structural performance (e.g. resulting in long lengths of unsupported piles, or shortened lengths of pier that might not be as flexible as in the original design)?
- Have deck joints been modified (e.g. by the installation of elastomeric plug joints in place of flexible or open type joints)?
- Has the structural action of the bridge under earthquake shaking been modified by a change to the points where the superstructure is anchored?

- Does the bridge possess any clearly critical details that could affect the performance of the structure during strong seismic shaking? For example:

  - Are there any breaks in continuity between superstructure elements (those with simply supported spans over intermediate piers, and across intermediate hinges within spans) that lack positive linkages?
  - Are the bearings likely to be stable under strong seismic shaking, or are they vulnerable and likely to fail by shear or overturning?
  - Are there any critical bracings that are likely to buckle, or whose end connections could control the performance of the bracing system?
  - Are there any details that could lead to consequential failures (e.g. as a result of impact between members)?

- What types of soils surround the bridge foundations and approaches? For example:

  - Are the piers founded in soft, flexible soils or in firm soils or gravel?
  - Are the soils around the piers likely to liquefy during strong shaking?
  - Are there signs of slumping of nearby soil slopes? Is slumping the result of the soft nature of the material or of river erosion?
  - Are there any steep slopes near the bridge that may collapse during strong shaking and cause blockage or structural damage?

- Does the bridge carry any significant services that are not recorded on the drawings?

3.6.5 Recording

All observations are to be recorded. The records will be used by others for the final evaluation and must therefore be self-explanatory. Observed items must be illustrated by fully annotated comprehensive photographs, with information such as item, direction of view and location (e.g. pier or abutment etc.) appended.

A sample form for recording information is attached in Appendix B.

3.7 Specialist Review of the Bridges

3.7.1 General

Completion of Stages 1 to 6 (Figure 1) will provide a preliminary list of seismic attribute grades. Anomalies are likely to arise if the SAG results are used as the sole basis of ranking the bridges because:

- Allocation of rating values for attributes depends on judgement in some areas;
- There can be key characteristics of a bridge that are not sufficiently reflected in the SAG method; and
- There may be characteristics of the bridge that represent vulnerability to strong earthquake shaking, but that are not readily identified by non-specialist personnel.

Stages 7 to 10 build on the results of the previous stages but incorporate specialist input to ensure that anomalies are identified and taken into account in deciding the most appropriate final recommended ranking. Because of the nature of the screening procedure, it is expected that conclusions will be reached on the basis of judgement rather than analysis.

3.7.2 Procedure

The review (Stage 7, Figure 1) shall be the responsibility of a specialist bridge engineer experienced in the seismic performance of bridges. The reviewer shall obtain such additional advice as is necessary in the geotechnical field to ensure that the preliminary assessments completed in Stages 2 to 5 are properly supplemented and adjusted when appropriate.

The drawings, bridge data forms and screening sheets used in Stages 1 to 5, and the results of site inspections carried out in Stage 6 (Figure 1) for all bridges shall be assembled. Reference is made in the following summary to Forms 1 to 4, which are attached in Appendix B of this manual.

The review shall comprise the following steps:

- Review the drawings, photographs and results of the site inspection (if any) to gain a knowledge of the structure;
- Note any significant structural characteristics that could affect the structure's seismic performance;
- Review the bridge data sheets (Form 1); check what geotechnical information is available and confirm the interpretation with geotechnical advice as appropriate;
- Review the basis on which bridges that were excluded from the ranking procedure in Stages 1 and 3 have been excluded (Form 2), and confirm or change the conclusion. Decide, for individual critical bridges in the area being assessed, whether the policy of total exclusion of bridges that are planned for replacement within five years should

apply. Initiate the SAGS procedure for previously excluded bridges for which it is agreed that inclusion is necessary;

- Review the content of Form 3 relating to approach settlement slabs and unlinked spans;
- Sign off all reviewed material.

3.8 Finalisation of the Seismic Attributes Grades

3.8.1 General

After completing the review, the bridge specialist will be in a position to modify the SAG values (Stage 8, Figure 1) to take account of factors where judgement indicates a change is appropriate.

3.8.2 Procedure

The following steps will be used to finalise the SAG:

- Review the rating values summarised in Form 4. Confirm or modify as appropriate, noting reasons for any modifications made. If necessary, discuss with the person who undertook the initial rating and agree a final result. Undertake a site inspection if necessary to resolve uncertainties. This would be in conjunction with any requirements for risk identification (3.9.3.3). Finalise the SAG value for the bridge;
- Modify the rating input values in the spreadsheet (Figure 5 and Appendix C) and derive the final SAG values. Sort the SAG values into descending order for the batch of bridges being considered;
- Sign off all reviewed material.

3.9 Risk Assessment

3.9.1 General

This section specifies the requirements of Stage 9 (Figure 1).

The outputs of Stages 1 to 8 (Figure 1) include standard information about each bridge pertaining to seismic performance and ranking for further consideration. The SAGS process uses only basic data and the results are therefore only indicative. The cost of retrofitting is not considered and the cost of damage is only considered indirectly. Both of these items can only be estimated more accurately after detailed analysis, which is beyond the scope of this initial screening procedure.

The purpose of Stage 9 is to use the information gathered in Stages 1 to 8 and to carry out qualitative risk assessments to assist with identifying the bridges, and the specific features of those bridges, that are most likely to return the greatest benefit from retrofitting. The economic ranking indicator (Stage 10) for each risk event is also a key item that is used for this purpose. The procedures will ensure that subsequent detailed analysis is carried out on the highest priority bridges first and only on bridges that justify it.

The risk assessment methodology and terminology to be applied is in accordance with standard AS/NZS 4360:1995 "Risk management", and subsequent amendments numbers 1 (December 1995) and 2 (January 1998). Tables 2 to 4 have been adapted from Appendix D of the standard.

3.9.2 Personnel

The risk assessment shall be the responsibility of a specialist bridge engineer who is experienced in the seismic performance of bridges (i.e. usually the same person as was responsible for Stage 7). Additional input shall be obtained as necessary in specialist areas such as geotechnical and economics.

3.9.3 Procedure

3.9.3.1 General

Screening consultants should be familiar with AS/NZS 4360:1995 and amendments before carrying out the risk assessment.

The risk assessment procedure to be applied is described below and is illustrated in Figure 3. The results shall be recorded on the risk register (Form 5 - Appendix B) and in the spreadsheet (Figure 6 and Appendix C). An example of a completed risk register is attached in Appendix F. An electronic version of Form 5 is available (see Appendix C) and completion electronically is recommended.

3.9.3.2 Bridges to be Assessed

The risk assessment shall be applied to all bridges that are not excluded from the ranking procedure (i.e. those for which a SAG is calculated in Stages 4 and 7 (Figure 1)).

3.9.3.3 Risk Identification

For bridges to which the risk assessment procedure is to be applied, the risk events (i.e. vulnerabilities to seismic damage) and their consequences for the structure shall be identified and described. These should come directly from the information gathered in Stages 1 to 7 but may require some further investigation or site visits. There may be more than one risk event per bridge and each shall be identified and evaluated separately.

For each risk event, assuming no retrofit to have been installed, the number of days (D') for which the detour will have to be used until the crossing can be reopened, with either a repaired or temporary crossing, shall be estimated and noted on Form 5. D' is used when applying Table 3 and for deriving the economic ranking indicator (Section 3.10). Note that other data (values of D and v_2) are required to be determined and added to Form 5 for *some* bridges – see Sections 3.10.1 and 3.10.2.

The output from this step is a list of risk events that may justify action to address, and associated information.

Figure 3 Risk Assessment Procedure

1. Identify Risk Events (Vulnerabilities to Seismic Damage)

- Describe the location in the structure, and the nature of the risk event. There may be more than one risk event per bridge, and each shall be separately identified.

↓

2. Estimate the Crossing Reinstatement Time for each Risk Event

- For each risk event estimate the number of days (D') for which the detour will have to be used until the crossing can be reopened with either a repaired or temporary crossing.

↓

3. Carry out the Risk Analysis – (i) Likelihood

- For each risk event estimate the critical peak ground acceleration (PGA) that will cause the risk event (Figure 4).
- Decide the relevant seismic zone factor (Z) for the site.
- Using Figure 4 determine the likelihood of the critical PGA occurring. Take account of the effect liquefaction might have on modifying the likelihood set out in Figure 4 (see 3.9.3.4).

↓

4. Carry out the Risk Analysis – (ii) Consequences

- For each risk event apply Table 2 to decide the consequences classification.
- For each risk event apply Table 3, using the values of D', and of AADT and EDT noted on Form 1 (Appendix B). Take account of the effect on access to critical facilities (see 3.9.3.4).

↓

5. Estimate the Level of Risk

- For each risk event apply the likelihood - consequences matrix in Table 4 to decide the level of risk associated with the risk event.

↓

6. Evaluate the Risks

- Evaluate the risks, in general noting the risk events with a significant or high likelihood for further consideration. Generally a low or moderate level of risk should be considered to be acceptable and the associated risk event need not be considered further.

↓

7. List the Treatment Options for the Risk Events

- For each risk event that was evaluated as having a significant or high likelihood, summarize the most suitable retrofit options for mitigating the risk. Estimate the rough order cost (ROC) for the retrofit, the number of days (D) required to reinstate the bridge to the existing traffic capacity, and the assessed journey speed (v_2) of traffic over the normal route, with a temporary crossing or a reduced level of service.

↓

8. Document the Information Derived from the Risk Analysis

- For each risk event enter the derived information into Form 5 (Appendix B) and into the summary spreadsheet (Figure 6).

3.9.3.4 Risk Analysis

(a) Introduction

Risk analysis may be undertaken to various degrees of refinement depending on the risk information and data available. To carry out a detailed quantitative seismic assessment of a bridge is generally time consuming, with the final result often bounded by a wide range of uncertainty. In particular there is considerable uncertainty about the ultimate strength performance of the range of concrete reinforcement details that have been used in the past. The displacement response of longer bridges that are not rigidly linked to piers and the interaction effects at abutments are other areas that are difficult to assess without very detailed analyses.

In the AS/NZS 4360:1995 qualitative risk assessment procedure, risk is assessed by considering both the likelihood and the consequences of a risk event. The risk event is then assigned a level of risk category by combining the likelihood and consequence using a matrix based on descriptive scales. For most bridges that are being screened it is expected that a qualitative risk assessment procedure will provide a sufficient indication of the level of risk.

For critically important bridges, or where a qualitative assessment does not clearly indicate that the risk event being considered has either a high or low risk priority, a quantitative approach involving simplified strength and displacement calculations may be used.

(b) Likelihood of Risk Event

The likelihood of a risk event (failure of a bridge span or component) in an earthquake depends on the following factors:

- Seismicity of the area;
- The length of exposure to risk, or remaining service life;
- Ground conditions; and
- Vulnerability of the span or component to earthquake loads and permanent ground deformations.

The overall likelihood of a risk event occurring is conveniently assessed by considering the two main factors separately. Firstly the vulnerability of the structure is considered and an estimate made of the ground shaking intensity, measured by the peak ground acceleration (PGA), likely to cause the risk event. The second step is to determine the probability of that PGA level occurring in the particular seismic zone during the remaining service life.

In the absence of a more detailed analysis, an estimate of the PGA at which the failure is expected to have a high probability of occurring can be assessed in a qualitative way using the relationships shown in Figure 4.

Figure 4 Likelihood of PGA being Equalled or Exceeded

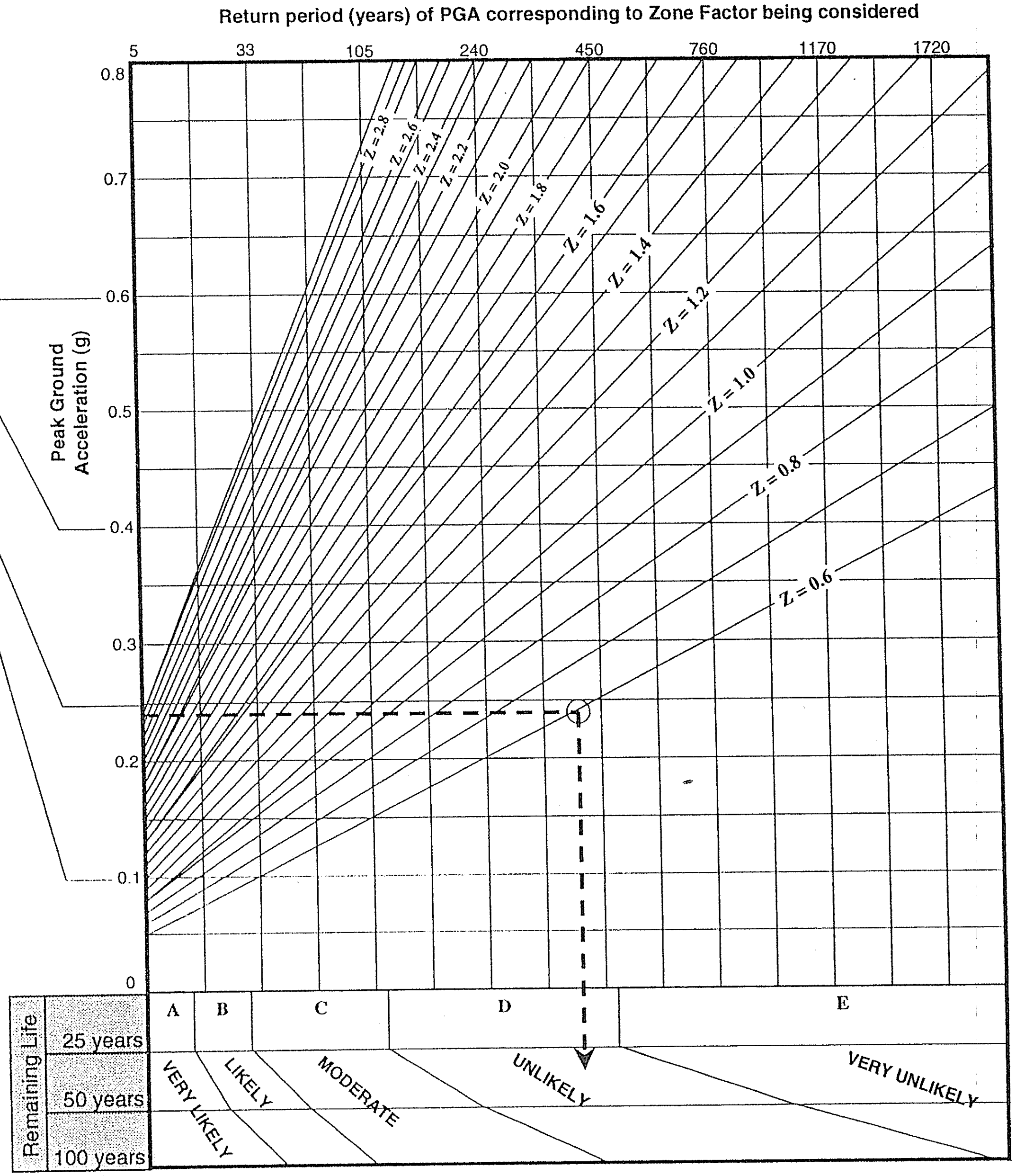
Descriptive Intensity of Ground Shaking and Equivalent Modified Mercalli Intensity	General Expected Performance of Bridge Structures (see Note)
Extreme Earthquake MMI = X	Severe damage in say 50% of bridges. Failures expected in older bridges.
Severe Earthquake MMI = IX	Moderate levels of damage to 70% of bridges and severe damage to 15% of bridges.
Strong Earthquake MMI = VIII	Moderate levels of damage to 20% of bridges. Significant damage expected in bridges with poor detailing and in older bridges with little or limited ductility.
Moderate Earthquake MMI = VII	Most bridges undamaged or sustain light damage but failures may result from very poor details.

Note: The expected performances noted apply primarily to pre-1960 bridges, which were generally designed for a standard value of earthquake loading. Bridges designed between 1960 and 1972 were generally detailed to a better standard and increasing recognition was given to seismic zoning for deciding the earthquake design loading. These bridges are likely to perform better than the pre-1960 structures.

Descriptive ranges of likelihood related to the probability of the event occurring within the life of the bridge

A	Very Likely	Probability greater than 0.9
B	Likely	Between 0.6 and 0.9
C	Moderate	Between 0.2 and 0.6
D	Unlikely	Between 0.05 and 0.2
E	Very Unlikely	Probability less than 0.05

– – – – – – Example shows assessment of the likelihood of a Peak Ground Acceleration of 0.24g occurring within 50 years in an area with a Zone Factor (Z) of 0.6.



The probability of a failure occurring may be increased by soil liquefaction or very weak foundation soils. This is particularly the case when the failure is related to excessive structural displacements. Liquefaction does not increase the intensity of ground shaking but may often increase the risk of damage and failure because it can induce large settlements and lateral spreading in the soil foundation. When the failure risk is likely to be increased by liquefaction this should be considered in applying Figure 4. For example, if the liquefaction risk is high, the PGA to cause failure should be taken as 0.1g lower than would be the case for no liquefaction risk.

The risk of liquefaction entered on the bridge data sheet (Form 1, Appendix B) should be used.

The overall likelihood of the risk event occurring shall be determined using Figure 4. This shows the likelihood (or probability) of the range of damaging PGA levels being equalled or exceeded within a particular seismic region, as defined by the zone factor (see Appendix D). In Figure 4, the likelihood is expressed in descriptive terms and the remaining service life is shown for a range of values from 25 to 100 years. The descriptive ranges of likelihood have the following bounds of probability of the event occurring within the life of the bridge:

very unlikely < 0.05 < unlikely < 0.2 < moderate < 0.6 < likely < 0.9 < very likely

Figure 4 is applied as follows:

- Estimate the PGA. This may be based on the descriptive intensity of ground shaking and general expected performance of bridges. It is suggested that PGA values of 0.20, 0.35, and 0.50 be adopted for MMIs of VII, VIII and IX respectively, unless the assessor sees characteristics that justify different values.
- Define the zone factor appropriate to the bridge site, as set out in the figure in Appendix D, and the expected remaining life for the bridge.
- From the PGA on the vertical axis, project horizontally across the graph to the zone factor line appropriate to the bridge site, and then vertically down to the relevant remaining life of the bridge, to derive the likelihood of the risk event.

While it is preferred that the value of the damaging PGA be used to derive the overall likelihood of the risk event occurring during the expected life of the bridge, in some cases it may be more appropriate to use judgement on the basis of the probability relationships set out above and tabulated at the bottom of Figure 4.

The values of return period noted along the upper edge of the chart are included as additional information, but reference to them is not directly necessary when relating a value of PGA to its likelihood of its occurrence in a particular seismic zone.

(c) Consequences of the Risk Event

The consequences of a risk event shall be assessed with regard to the impact on:

- Safety of people on or near the bridge;
- Cost of damage to the bridge;

- Disruption of traffic; and
- Disruption of lifelines

The consequences tend to be interrelated. For example, high damage costs will indicate a greater risk to safety and also greater disruption of traffic and lifelines.

The classifications to be assigned to the impact that the risk event has on each of the main consequences are given in Tables 2 and 3. In order to avoid unjustified complexity, bridge damage cost and safety are considered as a combined consequence. The disruption to lifelines is considered as an adjustment to the traffic disruption consequence.

The overall consequence classification to be used in the likelihood - consequence matrix is the more severe of the classifications determined by considering the impacts assessed by Tables 2 and 3 separately.

Table 2. Consequence Classifications Based on Bridge Damage and Safety

Extent of Damage to Bridge	Consequence Classification
Superficial damage, no disruption to traffic.	1. Insignificant
Significant damage to a single or two-span bridge requiring closure.	2. Minor
Significant damage in a number of locations on a bridge of more than two spans requiring closure.	3. Moderate
Damage requiring replacement of a single span.	4. Major
Damage requiring replacement of more than one span.	5. Catastrophic

Table 3. Consequence Classifications Based on Traffic Disruption and Lifelines

Extent of Traffic Disruption	Consequence Classification
$D' \times AADT \times EDT \leq 10^4$	1. Insignificant
$10^4 < D' \times AADT \times EDT \leq 10^5$	2. Minor
$10^5 < D' \times AADT \times EDT \leq 10^6$	3. Moderate
$10^6 < D' \times AADT \times EDT \leq 10^7$	4. Major
$D' \times AADT \times EDT > 10^7$	5. Catastrophic

where D' = number of days for which the detour will have to be used until the crossing can be reopened with either a repaired or temporary crossing.

AADT = annual average daily traffic count on the bridge. (see Appendix A, Section A1.2 (i))

EDT = "Extra distance travelled" ($d_1 - d_0$), (See Form 1, Appendix B).

When assessing the consequences of traffic disruption, routes to critical facilities that are likely to be required for emergency relief operations following an earthquake, such as hospitals, airports and rail and harbour terminals, shall be given special consideration and the consequences classification adjusted accordingly.

Where the failure or risk event is likely to lead to serious damage to critical telecommunication systems, power cables, water supply, or drainage utilities the consequence classification determined by Table 3 shall be adjusted to reflect the assessed seriousness of the loss of the utility.

(d) Likelihood – Consequences Matrix

The level of risk for each risk event shall be determined from the likelihood – consequences matrix in Table 4.

Table 4. Likelihood – Consequences Matrix for Estimating Level of Risk

Likelihood (Probability)	Consequences				
	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
A Very Likely	S	S	H	H	H
B Likely	M	S	S	H	H
C Moderate	L	M	S	H	H
D Unlikely	L	L	M	S	H
E Very Unlikely	L	L	M	S	S

Legend for level of risk categories: L = low M = moderate S = significant H = high

The overall level of risk, and the consequences and likelihood classifications shall be recorded on Form 5 (Appendix B). In addition, the PGA and zone factor used with Figure 4 shall be recorded.

The output of the risk analysis step is the estimated level of risk for each risk event.

3.9.3.5 Risk Evaluation

Risk evaluation involves comparing the level of risk identified during analysis with established risk criteria and deciding whether or not risks should be accepted. If resulting risks are deemed to be acceptable no further treatment is required.

Risk events in the low or moderate risk categories (i.e. as shaded in Table 4) should generally be considered to be acceptable with no further action required.

Risk events in the significant or high risk categories should generally have treatment options assessed as defined in 3.9.3.6.

The output of the risk evaluation step is the identification of risk events that require the assessment of treatment options.

3.9.3.6 Risk Treatment Options

In generic terms risk treatment involves identifying the range of options for treating risks, assessing them, preparing a risk treatment plan and implementing it (refer to Clause 4.5 of AS/NZS 4360:1995).

For this screening the scope of work on risk treatment options shall be limited to identification, description and an estimate of the rough order cost (ROC) of seismic retrofitting options, and also to estimating the values of D, D' and v_2 (see Section 3.10.2) for the bridge, assuming the risk event is not mitigated by retrofitting. These values shall be added to Form 5. Assessment of treatment options and the values of D and v_2 are only required for risk events with an unacceptable level of risk, as determined by the risk evaluation (Section 3.9.3.5). D' is required for use with Table 3.

The objective of this step is to identify possible treatment options and, combined with the other information, to provide the basis to determine rankings for detailed analysis.

Selection of risk treatment options should be based on the assessed benefits balanced against the cost of implementation. Some options where large reductions in risk can be obtained with relatively low expenditure should clearly be considered. Other options for risk reduction will be obviously unjustifiable on economic grounds. Between these extremes the decision on whether to proceed with risk reduction options will depend upon the results of detailed analysis, which is beyond the scope of this screening.

The primary output from this step is a list of treatment options, and their rough order costs, for risk events that may justify treatment.

3.10 Economic Ranking Indicator

3.10.1 General

The economic ranking indicator (ERI) is included in the procedures to take into account the comparative consequences and probabilities of loss of use of the bridges. It is calculated as the ratio of the dominant consequential cost (i.e. the cost for traffic to travel via the detour route or on the normal route with a reduced level of service) to the discounted cost to mitigate, by retrofitting, the risk event that is being considered. Although the ERI and a benefit/cost ratio are calculated on a similar basis the value of the ERI should not be construed as a proxy benefit/cost ratio. The economic ranking indicator shall be calculated for each risk event that has an unacceptable level of risk, as determined by the risk evaluation (Section 3.9.3.5) (i.e. only for those risk events for which risk treatment options are assessed in Section 3.9.3.6).

3.10.2 The Traffic Cost Parameter

$$\text{The Traffic Cost Parameter (TCP) (\$)} = D' \times AADT \times [0.35(d_1 - d_o) + a(d_1/v_1 - d_o/v_o)] + (D-D') \times AADT \times a(d_0/v_2 - d_0/v_0)$$

where D = number of days to reinstate the bridge to the existing traffic capacity.

D' = number of days for which the detour will have to be used until the crossing can be reopened, with either a repaired or temporary crossing.

AADT = annual average daily traffic count on the bridge.
d_o = length of the normal route, between the detour connection points (km).
d_1 = length of the detour (km).
a = time parameter, to be taken as 16 or 24, for urban or rural roads respectively.
v_0 = assessed journey speed of traffic over the normal route between the detour connection points under normal conditions (km/hr).
v_1 = assessed journey speed of traffic on the detour with diverted traffic (km/hr). If there are likely to be significant bottleneck effects on the detour, v_1 shall be reduced accordingly on the basis of judgement.
v_2 = assessed journey speed of traffic over the normal route, with a temporary crossing or a reduced level of service, between the detour connection points (km/hr).

3.10.3 The Economic Ranking Indicator

The Economic Ranking Indicator (ERI) = (PF x SLF x TCP) / (ROC)

where PF = probability factor from Table 5, using the PGA value determined for the risk assessment (Section 3.9.3.4(b)).
SLF = service life factor from Table 6.
TCP = traffic cost parameter (Section 3.10.2).
ROC = rough order cost of retrofit ($) (Section 3.9.3.6).

Table 5. Probability Factor (PF) = Probability of PGA being Equaled or Exceeded in 25 year Service Life.

PGA g	Seismic Zone Factor, Z											
	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.8
0.15	0.22	0.43	0.66	0.84	0.94	0.99	1.00	1.00	1.00	1.00	1.00	1.00
0.25	0.06	0.12	0.22	0.34	0.47	0.61	0.74	0.84	0.91	0.96	0.98	1.00
0.35	0.02	0.05	0.09	0.15	0.22	0.30	0.40	0.49	0.59	0.69	0.77	0.84
0.45	0.01	0.02	0.04	0.07	0.11	0.16	0.22	0.28	0.35	0.43	0.51	0.58
0.55	0.01	0.01	0.03	0.04	0.07	0.09	0.13	0.17	0.22	0.27	0.33	0.39

Note: Probability factors are based on the probability and risk information in Section 5.2.4 of the TNZ Bridge Manual. Intermediate values may be obtained by interpolation.

Table 6. Service Life Factor

Remaining Service Life (Years)	Service Life Factor (SLF)
6 to 10	0.5
11 to 15	0.7
16 to 25	0.9
>25	1.0

A service life factor as listed in Table 6 applies to bridges expected to be replaced between 6 and 25 years, for whatever reason.

3.11 Ranking for Further Analysis

3.11.1 General

For each batch of bridges assessed (i.e. usually by Transit New Zealand region) it is necessary to rank all risk events for which treatment options have been determined in 3.9.3.6, and then to rank the bridges associated with those risk events. Because different numbers and rankings of risk events will relate to each bridge, ranking the risk events provides the screening consultant with more information on which to rank the bridges for further detailed seismic analysis.

3.11.2 Ranking of the Risk Events

The ranking of risk events shall take account of the nature of their consequences and of relevant indicators as follows:

- whether the risk events relate to the safety of people;
- the ratio of the rough order cost of retrofit (ROC) to the depreciated value of the bridge;
- the ratio of the rough order cost of retrofit (ROC) to the replacement value of the bridge; and
- the economic ranking indicator (ERI).

Details of the current depreciated and replacement values of the bridges are available on application to the Regional Manager, Transit New Zealand.

Where it is likely that a number of people will be exposed to death or serious injury, then that risk event shall be placed with other similar events in the category with the highest ranking.

Notes on the reason for the selected ranking shall be included on Form 5, where appropriate. The ranking of risk events is necessarily subjective and shall be based on the judgement of the screening consultant.

The purpose of this step is to produce a ranked list of risk events that are considered to possibly justify seismic retrofitting. The list will be used to rank the list of bridges considered to warrant detailed seismic assessment. The purpose of ranking the risk events is to differentiate between the likely extent of retrofitting various parts of a structure to mitigate various different risks. For example it may be very cost effective to apply confining jackets to the piers of a bridge, but not to provide much more costly underpinning of the foundations, which may be subjected to damage by soil liquefaction, but with a very much lower risk.

3.11.3 Ranking of the Bridges for Further Detailed Seismic Assessment

3.11.3.1 Unlinked Spans

Unlinked spans shall be ranked in accordance with the criteria set out in 3.3.2. If the risk analysis shows no other risk events with a "significant" or "high" level of risk to be associated with the bridge, a detailed seismic assessment should not normally be necessary in order to decide whether to rectify the lack of linkages. The cost of such work may be sufficiently low to enable it to be installed as a maintenance item rather than as a capital cost item.

3.11.3.2 General Ranking of the Bridges

All bridges for which the risk analysis has resulted in a risk event with a "significant" or "high" level of risk shall be listed in order of decreasing rank for detailed assessment of their seismic performance and of their possible justification for seismic retrofit.

Ranking of the bridges necessarily depends to some extent on the subjective judgement of the screening consultant. For this reason the list of bridges shall be banded into groups of bridges judged to be of similar rank. While it is likely that some bridges will clearly warrant their various allocated relative ranks, it is likely that there will be bands of bridges that cannot be clearly separated. Such bands shall be identified, as this will help with making the final choice of structures for detailed seismic assessment.

As also required in 3.11.2 the ranking shall take account of the nature of the consequences of the risk events and shall consider mitigation of *safety* risks to be of higher rank than mitigation of *economic* risks.

The determination of rank shall take account of the following indicators:

- whether the consequences of the relevant risk events relate to safety or economics;
- the number and levels of risk events associated with each bridge;
- the values of economic ranking indicator (Section 3.10);
- the ratio of the rough order cost of retrofit to the depreciated value of the bridge;
- the ratio of the rough order cost of retrofit to the replacement value of the bridge;
- the seismic attributes grading (SAG);
- the relative integrity of the detour routes when the availability of a detour is a significant factor in deciding relative rankings of bridges for detailed seismic assessment; and
- the relative ease of providing a temporary bridge or bypass.