APPENDIX A

Details for Application of the Seismic Attributes Grading System

A.1. Rating the Attributes and Calculating Indices for the Variables

Reference to the Bridge Manual in this document should be interpreted as the Transit New Zealand Bridge Manual (1994) (ISBN 0-477-01697-9) and subsequent amendments.

A.1.1 Hazard Index

The *Hazard Index* reflects the seismicity and site risks for a particular bridge site and is based on four attributes:

- *Peak Ground Acceleration*
- *Remaining Service Life*
- *Soil Condition*
- *Risk of Liquefaction Effect*

Each of the attributes is discussed in detail below.

(i) *Peak Ground Acceleration* attribute

The *Peak Ground Acceleration* attribute reflects peak ground acceleration, seismic duration and the frequency of seismic activity. The zone factor (Z), defined in the Bridge Manual (see Appendix D), considers all these characteristics in a qualitative manner. The *Peak Ground Acceleration* attribute is based on a zone factor that originally ranged from 0.6 to 1.2 to reflect the variation of seismic risk within New Zealand. Subsequent seismological work has increased zone factor values above 1.2 for some areas. For rating this attribute a linear relationship is used normalised to a zone factor of 1.2, resulting in a *Peak Ground Acceleration* rating that exceeds 1.0 in some areas.

***Peak Ground Acceleration* rating is:**

$$= Z / 1.2$$

The attribute **weighting** is **40%**.

(ii) *Remaining Service Life* attribute

The *Remaining Service Life* attribute reflects the likelihood of a damaging seismic event occurring within the remaining service life of a bridge.

For rating this attribute a step function is used.

***Remaining Service Life* rating is:**

= **1.0** **Greater than 50 years of remaining service life**
= **0.7** **Remaining service life from 25 to 50 years**
= **0.5** **Less than 25 years of remaining service life**

The attribute **weighting** is **30%**.

(iii) *Soil Condition* **attribute**

Experience has shown that the degree of flexibility of subsoil can have a significant effect on the level of damage that can occur in an earthquake. This effect is reflected in the SAGS. For consistency in interpretation of soil type the definitions of subsoil categories in the Bridge Manual shall be used (Appendix D).

The advice of a geotechnical engineer or geologist should be obtained when completing this part of the procedure.

For rating this attribute a step function is used.

Soil Condition **rating is:**

= **1.0** **Flexible or deep soil site, or "Don't know"**

= **0.5** **Intermediate soil site**

= **0** **Rock or very stiff soil site**

The attribute **weighting** is **15%**.

(iv) *Risk of Liquefaction Effects* **attribute**

Earthquake induced liquefaction is the most significant of several types of earthquake induced ground effects that can affect a bridge.

For rating this attribute, a step function is used. The rating is based on a qualitative assessment of the risk of liquefaction, which will require subjective judgement. The advice of a geotechnical engineer should be sought, when completing this part of the procedure.

Definitions for the risk of liquefaction effects relate to the seismicity of the site, and the nature of the soils underlying the abutments or pier footings, or providing lateral support to piles.

The likelihood of effects on the bridge due to earthquake induced liquefaction, considering the seismicity of the site, the type and density of soils present, the thickness of liquefaction susceptible deposits, the likely consequences of liquefaction in terms of ground damage (subsidence, lateral spreading, loss of strength/stiffness) is :

- High — if the bridge is in an area of significant seismicity, with saturated very loose to medium dense sands, silty sands or non-plastic silts that have the potential to liquefy, and are present in sufficient thickness to give rise to significant subsidence, lateral spreading or loss of strength capable of causing damage to the bridge.
- Moderate — if the bridge is in an area of sufficient seismicity, with saturated medium dense to loose sands, silty sands or non-plastic silts that have the potential to liquefy, and are present in a thickness that can give rise to some limited subsidence, lateral spreading or loss of strength capable of causing damage to the bridge.

- Low — if the bridge is in an area of low seismicity, or with soils that are either dense, coarse (e.g. gravel), sufficiently fine grained (e.g. clay), plastic (e.g. plastic silt) or cemented (e.g. rock), such that they are unlikely to liquefy and cause ground damage or loss of strength / stiffness.

Risk of Liquefaction Effect **rating is:**

= **1** **High risk of liquefaction effect or "don't know"**

= **0.5** **Moderate risk of liquefaction effect**

= **0** **Low (or no) risk of liquefaction effect**

The attribute **weighting** is **15%**.

(v) **Hazard Index Summary**

The *Hazard Index* is the sum of:

Weighting		Attribute Rating		Weighted Rating
0.40	x	*Peak Ground Acceleration* rating	=	
0.30	x	*Remaining Service Life* rating	=	
0.15	x	*Soil Condition* rating	=	
0.15	x	*Risk of Liquefaction Effect* rating	=	
		TOTAL	=	*Hazard Index*

A.1.2 Importance Index

The *Importance Index* is based on six attributes to assess and reflect the consequences of bridge damage including public safety, the recognition that bridges form a vital link, and the socio-economic impacts and effects on road users. The attributes are:

- *Annual Average Daily Traffic Count (AADT) on Bridge*
- *Detour Effect*
- *AADT under Bridge*
- *Facility Crossed*
- *Strategic Importance*
- *Critical Utility*

The AADT and the Detour Effect attributes are combined for weighting purposes.

Each of the attributes is discussed in detail below.

(i) ***AADT on Bridge* attribute**

The *AADT on Bridge* attribute directly reflects the traffic use and hence the traffic disruption should damage occur. The AADT value used shall be the value calculated for the 12 months of the calendar year preceding that in which the screening is carried out.

For rating this attribute a linear relationship is used based on a maximum AADT of 30,000.

***AADT on Bridge* rating is:**

$$= \quad (AADT)/30{,}000 \qquad \leq 1$$

The *AADT on Bridge* rating is combined with the *Detour Effect* rating (see below).

(ii) ***Detour Effect* attribute**

The *Detour Effect* attribute reflects the level of inconvenience caused by the loss of a bridge. The basis of this attribute is the "extra distance travelled" (EDT = $d_1 - d_0$, Form 1 (Part 2), Appendix B). To assess this, consideration will need to be given to the origin and destination of the traffic, the condition of the detour route and its ability to accommodate the traffic use, and the likelihood that the detour route itself will have survived the seismic event. Consideration of these items is subject to considerable qualitative judgement. Some allowance will need to be made if local traffic is more significantly affected than is non-local traffic. An estimate of the percentage of the AADT due to local traffic will also then be required.

For rating this attribute a linear relationship normalised to 100 km is used.

The *Detour Effect* rating is:

$$= \quad (EDT)/100 \qquad \leq 1$$

The *Detour Effect* rating is combined with the *AADT on Bridge* rating (see above).

The **weighting** of (*AADT on Bridge* rating x *Detour Effect* rating) is **50%**.

(iii) ***AADT under Bridge* attribute**

The *AADT under Bridge* attribute reflects the traffic disruption in the vicinity of the bridge should the bridge fail. The other traffic users may or may not be on a state highway or motorway and the total AADT under the affected bridge shall be used.

For rating this attribute a linear relationship is used based on a maximum AADT of 30,000.

The *AADT under Bridge* rating is:

$$= \quad (AADT)/30{,}000 \qquad \leq \quad 1$$

$$= \quad 1$$ **when the bridge crosses over a railway line.**

The attribute **weighting** is **10%**.

(iv) *Facility Crossed* attribute

The *Facility Crossed* attribute reflects the potential for loss of life beneath the bridge, property damage, and individual or business financial losses. In assessing the width of the affected land, 2 x height of structure above the ground plus the width of the structure should be adopted.

For rating this attribute a step function is used.

***Facility Crossed* rating is:**

=	**1.0**	**Where residential, operational facilities involving a large gathering of people, commercial or industrial facilities would be affected by collapse;**
=	**0.5**	**Where parking or storage facilities would be affected by collapse;**
=	**0**	**Other uses or railway**

In the case of a bridge that crosses a road, railway line or waterway a rating of 0 should be assigned, since these items are covered by the "AADT under" attribute.

The attribute **weighting** is **15%**.

(v) *Strategic Importance* attribute

The *Strategic Importance* attribute directly reflects the importance of the route as a national traffic lifeline. The state highway volume classes and heavy vehicle intensities (v.p.d.) shown in Figures 2 and 3 of the Transit New Zealand National State Highway Strategy publication[1] shall be used as the basis for this attribute (Appendix E).

For rating this attribute a step function is used.

***Strategic Importance* rating is:**

Rating	Volume Class of Highway
1.0	**motorway or urban or over 10,000 v.p.d. or over 600 heavy v.p.d.**
0.9	**4,000 - 10,000 v.p.d. or 400 - 600 heavy v.p.d.**
0.7	**1,000 - 4,000 v.p.d. or 200 – 400 heavy v.p.d.**
0.6	**less than 1,000 v.p.d. less than 200 heavy v.p.d.**

[1] "National State Highway Strategy", Transit New Zealand. June 1998

If the numbers of vehicles and heavy vehicles per day result in different rating values for a bridge, the higher rating value shall be used.

The attribute **weighting** is **15%**.

(vi) *Critical Utility* attribute

The *Critical Utility* attribute reflects the importance of the other lifelines that are carried on the bridge and that would be disrupted should the bridge be significantly displaced. The lifelines that are to be considered in rating this attribute include:

- water supply
- sewerage
- gas

Only utilities in pipes with an internal diameter of 100 mm or more are considered in rating this attribute.

Should any of these utilities be carried on a bridge then a high rating should be given. However, some state highway bridges may carry utilities that service only a small population. In these cases it may be appropriate to check with the utility authority whether temporary disruption would be critical or not and rate the attribute accordingly.

For rating this attribute a step function is used.

***Critical Utility* rating is:**

= 1.0 **Critical utility is carried on the bridge**

= 0 **Critical utility is not carried on the bridge**

The attribute **weighting** is **10%**.

(vii) Importance Index Summary

The *Importance Index* is the sum of:

Weighting		Attribute Rating		Weighted Rating
0.50	x	*AADT on Bridge* rating x *Detour Effect* rating	=	
0.10	x	*AADT under Bridge* rating	=	
0.15	x	*Facility Crossed* rating	=	
0.15	x	*Strategic Importance* rating	=	
0.10	x	*Critical Utility* rating	=	
		TOTAL	=	*Importance Index*

A.1.3 Vulnerability Index

The *Vulnerability Index* is based on eight attributes to define and reflect structural details that have a potential for damage. The index also reflects the potential cost of retrofitting a bridge. These attributes are based on the experience gained from the performance of bridges in earthquakes, and allow for the interaction of structural components. The attributes used are:

- *Year Designed*
- *Superstructure Hinges*
- *Superstructure Overlap on Supports*
- *Superstructure Length*
- *Pier Type*
- *Skew*
- *Abutment Type*
- *Other Feature*

The *Other Feature* attribute allows the screening consultant the discretion to identify the presence of a vulnerable feature, whether this is an abutment/approach instability (other than liquefaction), bearing details, diaphragms, inadequate linkages or the general bridge condition.

In the SAGS emphasis is placed on the general "looseness" of the superstructure relative to its supports. This is reflected in the *Hinges, Overlap* and *Length* attributes because a "loose" bridge allows a greater relative movement during an earthquake and is more likely to suffer a "drop" type failure.

The screening consultant must inspect drawings of the structure (preferably as-built revisions) because bridge details have important effects on the performance of the structure during an earthquake. Knowledge of any structural modifications made since construction is required. The consultant will also need to be conversant with, or have access to an advisor with experience of, how structures respond in an earthquake.

Each of the attributes is discussed in detail below.

(i) *Year Designed* Attribute

The *Year Designed* attribute reflects the main stages in the development of seismic design and detailing. Experience has shown that structure performance and hence the level of damage in a seismic event is strongly dependent on the overall design philosophy and on the design of individual elements. In New Zealand the main code changes occurred in 1933, following the Napier earthquake, and in 1972 when the Highway Bridge Design Brief (MWD 1972) was issued. The distinction between the year designed and the year constructed must be recognised, and the year designed is to be used.

The 1956 Bridge Manual did not contain the requirement for linkages between superstructure elements that was included in the 1933 design instruction, but this structural feature is checked during the initial bridge screening.

For rating this attribute a step function is used.

Year Designed **rating is:**

= **1.0** **Bridge designed before 1933**

= **0.5** **Bridge designed in the years 1933-1972**

= **0** **Bridge designed after 1972**

The attribute **weighting** is **25%**.

(ii) ***Superstructure Hinges*** **attribute**

The *Superstructure Hinges* attribute refers specifically to in-span hinged or movement joints within the main longitudinal load-bearing structural members. It accounts for the "drop type" failure, which can be a problem with this detail during earthquakes.

This attribute excludes stepped seatings, that commonly exist at piers or abutments, as these are specifically covered in the *Superstructure Overlap* attribute. It also excludes articulated deck slabs with continuous longitudinal reinforcing steel passing through the "hinges".

The number of hinges is the total number of in-span locations at which hinges across the full width of the superstructure occur within the length of the bridge. For rating this attribute a step function is used.

Superstructure Hinges **rating is:**

= **1.0** **If there are two hinges or more within a bridge superstructure**

= **0.5** **If only one superstructure hinge is present**

= **0** **If no superstructure hinges are present**

The attribute **weighting** is **8%**.

(iii) ***Superstructure Overlap on Supports*** **attribute**

The *Superstructure Overlap on Supports* attribute reflects the potential "drop type" failure at piers or abutments that can be a problem during earthquakes. The attribute rating is based on the minimum overlap requirements for the span/support overlap specified in the Bridge Manual. The bearing overlap, also specified in the Bridge Manual, is not considered critical for the purposes of the SAGS.

Inter-span linkages are a low-cost insurance against loss of span support, and it is appropriate to adopt a conservative approach to rating this attribute. The strength of linkages and span overlaps in older bridges do not necessarily meet the current specification as set out in the Bridge Manual. A "no linkage" situation should be assumed and a high rating given for the *Other Feature* attribute where the linkage capacity is clearly undersized, significantly deteriorated or has an inadequate load path (e.g. if a holding-down bolt has inadequate lateral support from pier cap concrete). In extreme circumstances the screening consultant may rank the structure under the initial screening procedures as if it lacks connections between superstructure elements. For the situations where the linkage capacity is marginally

inadequate the choice of whether a linkage system is acknowledged or not is at the screening consultant's discretion.

For rating this attribute a step function is used. As a bridge may have different details at different locations, with different rating values, the highest rating value should be used.

Superstructure Overlap on Supports **rating is:**

No linkage system or loose linkage system present:

= 1.0 Overlap less than 400 mm
= 0 Overlap 400 mm or more

Linkage comprising holding-down bolts in shear:

= 1.0 Overlap less than 300 mm
= 0 Overlap 300 mm or more

Tight tension linkage system present

= 1.0 Overlap less than 200 mm
= 0 Overlap 200 mm or more

The attribute **weighting** is **10%**.

(iv) *Superstructure Length* **attribute**

The *Superstructure Length* attribute reflects:

- The risk of differential seismic response increasing with the length;
- The diminished transverse damping provided by the approach fills as bridge length increases;
- The greater potential for a "drop type" failure because of the accumulation of longitudinal displacements of multiple simply-supported spans, possibly resulting in overlap provisions being exceeded;
- The increasing degree of difficulty to provide a temporary crossing with increasing length of superstructure.

The length of superstructure shall be measured as the distance between the abutments, to be taken either as between the centrelines of the bearings (where applicable), or to the ends of the superstructure if it is effectively monolithic with the abutment.

For rating this attribute a step function is used.

Superstructure Length **rating is:**

= **1.0** **Bridge length exceeding 200 m**

= **0.8** **Bridge length from 100 m to 200 m**

= **0.6** **Bridge length from 40 m to less than 100 m**

= **0.2** **Bridge length from 20 m to less than 40 m**

= **0** **Bridge length less than 20 m**

The attribute **weighting** is **12%**.

(v) ***Pier Type* attribute**

The *Pier Type* attribute reflects the different seismic responses and the different degrees of reserve against sudden failure, which are inherent in the typical structural forms used. If a bridge includes various pier types, each with a different rating value, the highest rating value shall be used.

For rating this attribute a step function is used.

***Pier Type* rating is:**

= **1.0** **Single column**

= **0.5** **Multi column, or slab pier on pile foundation**

= **0.25** **Slab pier on spread footing foundation**

The attribute **weighting** is **15%**.

(vi) ***Skew* attribute**

The *Skew* attribute reflects the likely accumulation of eccentricity and torsion effects that may not have been fully allowed for in the original design. Bridge skews tend to be increased during strong earthquake shaking.

For rating this attribute a linear relationship is used, normalised to 90°.

***Skew* rating is:**

= $\theta / 90 \leq 1$

θ = the angle in degrees between the perpendicular to the centreline of the roadway at each abutment, and the line of the back face of the abutment. If θ at each abutment differs, the greater value shall be used.

The attribute **weighting** is **5%**.

(vii) *Abutment Type* attribute

The *Abutment Type* attribute reflects that bridges with monolithic abutments perform well in earthquakes whereas those without them are more susceptible to damage. In this context a monolithic abutment is defined as one to which the superstructure is tightly linked, so that significant independent horizontal movement of the superstructure relative to the abutment during earthquake shaking is unlikely. To be considered as monolithic the abutment backwall must be in intimate contact with the approach fills over the full depth or more of the superstructure, and the full width of the main longitudinal members.

***Abutment Type* rating is:**

= 1.0 Non-monolithic abutments

= 0 Monolithic abutments

The attribute **weighting** is **10%**.

(viii) *Other Feature* attribute

The *Other Feature* attribute allows the screening consultant the discretion to reflect any other feature that is likely to make the bridge vulnerable to damage. It is expected that these will be different from the attributes used in the SAGS, except for linkages (refer *Superstructure Overlap on Supports* attribute). At least the following features should be considered:

- Linkages (capacity, condition, ductile capability);
- Diaphragms (adequacy for second order effects);
- Bearings (susceptibility to damage);
- Standard of important details;
- The overall general condition of the bridge;
- Approach stability (e.g. landslides that may be activated by a seismic event). Note that liquefaction is covered separately and should not be included in this attribute;
- Significant horizontal curvature.

For this attribute a rating value between 1.0 and 0 is assigned using judgement based on the consequences of damage to the feature or features identified. For example, if collapse would result, a value of 1.0 should apply. If the bridge could remain in unrestricted use, a value of 0 should apply. A value between 0 and 1.0 should be selected if the bridge would be temporarily out of use, or be subject to a local restriction.

***Other Feature* rating is:**

= 1.0 (maximum) If vulnerable features are present

= 0 If a vulnerable feature is not present

The attribute **weighting** is **15%**.

Vulnerability Index Summary

The *Vulnerability Index* is the sum of:

Weighting		Attribute Rating		Weighted Rating
0.25	x	*Year Designed* rating	=	
0.08	x	*Superstructure Hinges* rating	=	
0.10	x	*Superstructure Overlap* rating	=	
0.12	x	*Superstructure Length* rating	=	
0.15	x	*Pier Type* rating	=	
0.05	x	*Skew* rating	=	
0.10	x	*Abutment Type* rating	=	
0.15	x	*Other Feature* rating	=	
		TOTAL	=	*Vulnerability Index*

A.2 Calculating and Summarising the *Seismic Attributes Grade*

***Seismic Attributes Grade* is:**

= ***Hazard Index* x *Importance Index* x *Vulnerability Index***

Form 4 (Appendix B) shall be completed and the form signed off for inclusion in the bridge record file. An electronic spreadsheet version of this form is available on diskette and it is recommended that the form is completed electronically.

The seismic attributes grades shall also be derived by entering the attribute rating values in the spreadsheet provided with this document (Figure 5 and Appendix C). Use of this summary spreadsheet facilitates ready modification of the rating values, but also allows the priority order to be easily derived by sorting the table on the SAG values.