Fraser Thomas ENGINEERS • RESOURCE MANAGERS • SURVEYORS	**GUIDANCE DOCUMENT ON CANTERBURY EARTHQUAKE REMEDIATION - SECTIONS 7 AND 8**		
Client	Earthquake Commission		
Subject	Engineering Advisory Group		
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Section 7 : Recommended Foundation and Flooring System, and Options for Houses Being Completely Rebuilt

Reference to pros-cons table, particularly relating to performance measure.

Refer to BJB's preliminary scoping comments made to 7/10 meeting to effect that :

(a) geotechnical engineers will need to define eg 95% ground deformation profile that may occur over the future life of the building, the ground slab (ribbed or otherwise) will naturally deform to fit that profile, with normal allowances for relative stiffness (ie soil/structure interaction) problem;

(b) conforming foundation systems will need to be stiff enough to limit excessive angular distortion in supported partitions under the specified "ground deformation profile";

(c) these angular distortion limits will be matched to superstructure material by type :

(i) external articulated brick veneer (1:500)* or weatherboard cladding (1:250)*;

(ii) internal GIB®-lined partitions (1:300)*; and

(d) all of this follows the design process specified within eg AS 2870 covering foundations for expansive soil sites.

*NB : These are notional values inserted in haste, and BJB needs to review, but they are of correct one.

Reference in B1/VM4 to the deformation limit of 1:240 (25 mm in 6 m). Need to clarify, but do not believe this is intended to be an amenity limit per se - it is more a structural distortion limit to reflect normal variability in the strength and stiffness of foundation soils. This will reflect in the differential settlement that a supported structure, such as a moment-resisting gravity-loaded frame, must be able to withstand without reaching applicable limit states, eg excessive cracking at beam column joints. It reflects extreme cases for unfactored (serviceability) loads which supported elements should be able to withstand without alternative provisions being made in the structural solution.

Parallel Standards, eg AS 1170.0 Table C3.1 (?) etc, may better reflect amenity Standards, and suggests floor distortion limits of around 1:300 (?) for peak gradient arising from beam sag, but note there is no comparative value for differential settlement between columns.

I suggest there should be maximum differentials based on something like :

(a) gradient of eg 1:400 (15 mm in 6 m) due to support settlement; and

(b) absolute differential of eg ±10 mm across a discrete floor plate, eg single dwelling.

NB : Refer FTL/BJB's paper on expansive soils etc for discussion.

In addressing the applicable structural performance standards, eg B1, it should be noted that deformations in eg foundations will often have consequential effect on supported elements, such as external claddings. It is those consequential effects that will lead to other non-compliances within the Building Code, such as given by the following examples :

(a) Extensive cracking in brick veneer weathershield will lead to weathertightness failure of the external envelope as a consequence.

(b) Extensive distortion of external wall framing may distort door and/or window openings beyond their normal adjustment tolerances, and cause water ingress through the external envelope as a consequence. Hence more stringent distortion limits might apply to external envelope than for internal partitions.

(c) Excessive dish-type settlement in eg ground bearing slabs may have consequential effects on other elements. It might induce lateral distortion in internal partitions which form part of the dwelling's lateral backing system. It might also lead to a disconnection (or weakening) of the top plate of the bracing panel where it connects into the ceiling diaphragm. Both of these have the potential to reduce the lateral bracing resistance available in the system.

In addressing these points, it is necessary to consider :

(a) the likely ground deformation over time due to loads applied by the building structure, eg immediate and consolidation settlements;

(b) the likely ground deformation over time due to normal environmental effect on the foundation soils, eg seasonal swell/shrink, erosion, subsidence; and

(c) the likely ground deformation over time due to abnormal environment occurrences, eg extremem swell shrink arising from extreme drought, significant erosion, lateral spreading from eg landslips, loss of reliable bearing support due to liquefaction arising from earthquake.

Normal design processes used by structural engineers adequately address (a). The indicators within eg B1/VM4 Appendix B1 suggest methods of addressing (b) and perhaps (c), but often these are not sufficiently addressed in design.

It will be necessary to define "distortion profiles" with remediated foundation systems on liquefaction-prone ground that will satisfy the anticipated long-term performance requirement for superstructures, in a similar manner to that proposed within AS 2870 for expansive soil site conditions.

Section 8 : Proposed Arrangements for Structural Engineering and Geotechnical Input

Taking some of the concepts from my notes for Section 7, the following indicative table can be developed :

NB : For discussion only - distortion limits suggested are indicative only, and will need appropriate sourcing.

Soil/Foundation/Superstructure : Interaction Template (very preliminary !)

Structure Element	***Geotechnical Input***		***Structural Element***	
	Load/Environmental Effect	***Performance Threshold***	***Design Action***	***Performance Threshold***
1. Pile Foundation	*(a) Gravity/non-seismic (SLS)* *(b) Gravity/seismic (ULS)*	*End Bearing/Shaft Friction Parameters* *S = 60 mm in 1.5 m* *S = 10 mm in 1.5 m*	*Pile Axial Load* *SLS* *ULS*	*Pile Axial Settlement* *S = 60 mm* *S = 10 mm*
2. Ground Bearing Slab System (incl thickenings)	*(a) Gravity/non-seismic (SLS)* *(b) Gravity/seismic (ULS)*	*Subgrade Angular Distortion* *S/L = 1:400* *S/L = 1:240*	*Foundation Beam Flexure M** *S/L = 1:240*	*Foundation Beam Distortion* *S/L = 1:400* *S/L ≤10 mm*
3. Perimeter Beam (support, eg claddings)	*(a) Gravity/non-seismic (SLS)* *(b) Gravity/seismic (ULS)*	*Subgrade Angular Distortion* *S/L = 1:500* *S/L = 1:300*	*Foundation Beam Flexure M** *S/L = 1:240*	*Foundation Beam Distortion* *S/L = 1:400* *S/L ≤10 mm*

Notes

1. *Geotechnical engineer identifies distorted ground profile for ULS design condition corresponding to potential deformation in liquefaction condition at the site over 50-year period (design life of dwelling).*
2. *Structural engineer specifies stiffness of foundation system that limits angular distortion to values for corresponding SLS case which correspond to the performance thresholds for (a) external cladding (material specific, including provision for articulation as appropriate) and internal partitions (material specific).*
3. *S = reference point settlement, L = separation between adjacent reference points, ULS = ultimate limit state, SLS = serviceability limit state.*

Draft Section 4 Text from John Leeves

Performance Expectations for Foundations and Flooring Systems

BACKGROUND

Generally three broad groups of buildings exist:

A Timber framed suspended timber floor structures
B Timber framed suspended timber floor structures with perimeter concrete footing
C Timber framed dwelling on concrete floor

The damage observed to Group A & B type buildings is generally easier and less costly to repair. Group C type buildings are typical of the newer subdivisions of Kaiapoi, Bexley and Brooklands, with a significant number of buildings less than 10 years old. These buildings are typically supported on a shallow reinforced concrete perimeter strip footing, with concrete cast-on-grade floors. The floors are, in many cases, unreinforced, and not tied in to the perimeter foundations. These foundation and flooring systems have been observed to perform poorly in those areas that have undergone land deformation. In addition such buildings will be difficult and more costly to repair.

The relevant building code NZS 3604: 1999 and the seismic loadings code NZS 1170.5:2004 requires minimum ultimate limit state (ULS) design performance requirements for buildings to protect the occupants for levels of shaking at, or less than, ULS (i.e. avoidance of collapse of the structure). At these levels of shaking, however, damage is expected. Where buildings can be repaired on their existing foundations, it is likely that the damage to the buildings is not so severe that they needed to be evacuated (i.e. no red or yellow notices) and that the buildings have remained habitable. Accordingly, buildings affected by the Darfield Earthquake could be considered to have generally performed adequately under the design (ULS) earthquake, and hence can be considered to have complied with the relevant building code.

Where buildings require demolition because they cannot be repaired within the building value, but have remained habitable (i.e. a green notice), these buildings could also be considered to have complied with the Building Code.

Dr David Hopkins (Department of Building and Housing) made the following summary of the views of experts who are involved in examining the impact of the earthquake and gathering data to better understand its implications.

> *Comparing the intensity of ground shaking in the 4 September earthquake with that used in the design of new buildings and infrastructure, the building performance and damage caused suggests that this was a moderate earthquake with much less impact than expected from a "design" earthquake.*
>
> *It is most unlikely that earthquake design standards for buildings and infrastructure in Christchurch / Canterbury need to be changed as a result of the earthquake. There is no reason evident so far to suggest they should be increased or decreased. The performance of buildings and infrastructure was generally as expected by experts.*

The earthquake is a reminder that good engineering design and good quality construction is important.

It is also possible to reduce the damage to buildings caused by liquefaction and lateral spreading by using robust foundations, tying of floor slab to buildings, using piled foundations, ground improvement or densification of the liquefiable layers are well accepted measures. The choice of method will depend on cost-effectiveness.

PERFORMANCE EXPECTATIONS

The land affected by liquefaction from the Darfield Earthquake is generally underlain by a 1 to 2 m stiff unsaturated upper layer overlying saturated fine grained sands or silty sands extending up to 10 m depth. We understand from claimants that anecdotally the land is still settling. Based on this information we expect that pore pressures in the liquefied zone have not fully dissipated and the liquefied sands have not yet returned to their pre-earthquake densities. We expect that by far the majority of the liquefaction induced settlement has occurred with the remaining movements expected to be completed in the next few months. Survey monitoring and geotechnical investigations have been initiated to confirm this.

On this basis we recommend that any repair work to dwellings in the liquefied areas be undertaken once final settlements have ceased or the works be undertaken in a manner that can accommodate additional minor settlements (< 10 mm). In areas where the upper soil layer has a higher clay content soil movements from seasonal wetting and drying (shrink/swell movements) could be expected to occur. These movements could be up to 30 mm but would generally be < 10 mm in most areas of Christchurch. Based on the above, repaired or re-constructed floor systems should be designed to accommodate minor ground level fluctuations as have historically occurred.

The concrete slabs that appear to have performed best are a stiff reinforced slab (ribraft or similar). Unreinforced slabs and slabs that are not tied into the perimeter concrete footing have performed poorly. The rounded river metal typically used as fill beneath concrete slabs in Christchurch has also performed poorly with densification of the metal occurring during the earthquake causing additional slab settlement to occur.

Accordingly any reconstructed slabs would likely perform better in a future seismic event if they were:

1. Stiff and rigid (like Ribraft)
2. Reinforced adequately
3. Were placed on well compacted gravels (rather than uncompacted rounded aggregate).