

APPENDIX A-V

DETAILED ENGINEERING

CHECK LIST FOR DESIGNING TO COUNTERACT NATURAL HAZARDS

(Earthquakes, Hurricanes and Torrential Rains)

Appendix V constitutes a comprehensive list of issues to be addressed in designing to counteract the effects of natural hazards. This is a very complex process, if done properly and thoroughly. Thus, check lists are invaluable to the exercise. For any particular project all of the items may not be relevant, but excluding item from a comprehensive list is always easier than adding relevant items to a short list.

1 Seismic, Hurricane and Rain Hazards

1.1 History

- 1.1.1 Earthquake
- 1.1.2 Hurricane
- 1.1.3 Torrential rain

1.2 Geology

1.3 Tectonics

1.4 Design characteristics

- 1.4.1 Earthquake design characteristics
- 1.4.2 Hurricane design characteristics
- 1.4.3 Design characteristics for torrential rains

2 Site Conditions

2.1 Soils

- 2.1.1 Liquefaction
- 2.1.2 Seismic characteristics

2.2 Topography

- 2.2.1 Landslide
- 2.2.2 Building on slopes
- 2.2.3 Topographic effect on wind speed
 - 2.2.3.1 Ridges
 - 2.2.3.2 Valleys
- 2.2.4 Flood prone areas
 - 2.2.4.1 Torrential rains
 - 2.2.4.2 Storm surge
 - 2.2.4.3 Tsunami

2.3 Other Factors

- 2.3.1 Corrosive Environments
 - 2.3.1.1 Coastal areas
 - 2.3.1.2 Industrial and other chemical pollutants

3 The Client's Brief

- 3.1 Function
- 3.2 Cost
- 3.3 Reliability
 - 3.3.1 Serviceability for different components of the facility
 - 3.3.2 Safety for different components of the facility

4 Design Philosophy

- 4.1 Performance in moderate and frequent hazardous events
 - 4.1.1 Protection of property
 - 4.1.1.1 Cost of repairs should be minor
- 4.2 Performance in strong, rare, hazardous events
 - 4.2.1 Saving lives
 - 4.2.2 Repairable damage (very critical facilities in earthquake events)
 - 4.2.3 Protection of all property in hurricanes and torrential rains
 - 4.2.4 Protection of all property in earthquakes (base isolation)
- 4.3 Critical areas or components of facilities
- 4.4 Post-yield behavior of structural elements
 - 4.4.1 Ductility
 - 4.4.2 Energy absorption
 - 4.4.3 Deformations
- 4.5 Building Envelope for Hurricanes
 - 4.5.1 Windows, external doors and roof cladding

5 Choice of Form or Configuration

Poor design concepts can be made safe but are unlikely to perform really well in strong earthquakes

- 5.1 Failure modes
 - 5.1.1 Redundancy
 - 5.1.2 Accidental strength
 - 5.1.3 Column capacities (and those of other vertical load-carrying elements) – New Zealand's "capacity design"
 - 5.1.4 Designing for failure
 - 5.1.4.1 Avoid failure in vertical, shear and compression elements

- 5.1.4.2 Avoid brittle failure
 - 5.1.4.3 Avoid buckling failure
 - 5.1.5 For hurricane forces design for repeated loads without degradation
- 5.2 Geometric issues
- 5.2.1 Simplicity and symmetry
 - 5.2.2 Long buildings to be structurally broken (separation gaps of sufficient widths to avoid Hammering earthquakes)
 - 5.2.3 Elevation shape
 - 5.2.3.1 Sudden steps and setbacks to be avoided
 - 5.2.4 Uniformity
 - 5.2.4.1 Distribution of structural elements
 - 5.2.4.2 Principal members to be regular
 - 5.3.4.3 Openings in principal members to be avoided
 - 5.2.5 Continuity
 - 5.2.5.1 Columns and walls from roof to foundation (without offsets)
 - 5.2.5.2 Beams free of offsets
 - 5.2.5.3 Coaxial columns and beams
 - 5.2.5.4 Similar widths for columns and beams
 - 5.2.5.5 Monolithic construction
 - 5.2.6 Stiffness and slenderness ($h > 4b$)
 - 5.2.6.1 Stiffness versus flexibility
 - 5.2.6.2 Maintaining the functioning of equipment
 - 5.2.6.3 Protecting structure, cladding, partitions, services
 - 5.2.6.4 Resonance
 - 5.2.7 Favourable and unfavourable shapes
 - 5.2.7.1 Square
 - 5.2.7.2 Round and regular polygons
 - 5.2.7.3 Rectangular
 - 5.2.7.3.1 Aspect ratios
 - 5.2.7.4 **T** and **U** shaped buildings
 - 5.2.7.4.1 Aspect ratios
 - 5.2.7.4.2 Deep re-entrant angles
 - 5.2.7.4.3 Establish structural breaks (create rectangular plan forms – see 5.2.2)
 - 5.2.7.5 **H** and **Y** shaped buildings
 - 5.2.7.5.1 Aspect ratios
 - 5.2.7.5.2 Deep re-entrant angles
 - 5.2.7.5.3 Establish structural breaks (create rectangular plan forms – see 5.2.2)
 - 5.2.7.6 External access stairs
 - 5.2.7.7 False symmetry – regular perimeter masking irregular positioning of internal Elements
 - 5.2.8 Soft storey
 - 5.2.9 Cantilevers to be designed conservatively
 - 5.2.10 Desirable roof shapes for hurricane resistance
 - 5.2.10.1 Steep pitched roofs (20-40 degrees)
 - 5.2.10.2 Hipped roofs are preferable
 - 5.2.10.3 Gable roofs are an acceptable compromise
 - 5.2.10.4 Mono-pitched roofs are undesirable

- 5.2.10.5 Boxed eaves recommended for overhangs exceeding 450mm
- 5.2.10.6 Parapets reduce wind uplift
- 5.2.10.7 Ridge ventilators reduce internal pressures

5.3 Distribution of horizontal load-carrying functions in proportion to vertical load-carrying functions (avoid the overturning problem)

5.4 Structural system to be agreed by design team

- 5.4.1 Moment-resisting frames
- 5.4.2 Framed tubes
- 5.4.3 Shear walls and braced frames
- 5.4.4 Mixed systems

6 **Choice of Materials**

6.1 Local availability

6.2 Local construction skills

6.3 Costs

6.4 Politics

6.5 Ideal properties

- 6.5.1 High ductility
- 6.5.2 High strength-to-weight ratio
- 6.5.3 Homogeneous
- 6.5.4 Ease of making connections
- 6.5.5 Durable

6.6 Order of preference for low-rise buildings

- 6.6.1 In-situ reinforced concrete
- 6.6.2 Steel
- 6.6.3 Reinforced masonry
- 6.6.4 Timber
- 6.6.5 Prestressed concrete
- 6.6.6 Precast concrete
- 6.6.7 Unreinforced masonry not recommended

6.7 Light-weight roof cladding of pitched roofs

- 6.7.1 Method of fixing critical to roof performance

7 **Construction Considerations**

7.1 Supervision

7.2 Workmanship

7.3 Ease of construction

8 **Components**

8.1 Base isolators and energy-absorbing devices (to be given consideration)

8.2 Foundations

8.2.1 Continuous

8.2.2 Isolated (to be avoided)

8.2.3 Piled

8.3 Movement and separation joints

8.4 Diaphragms

8.5 Precast concrete

8.6 Welded beam-column joints for moment-resisting steel frames (to be avoided)

8.7 Shear walls and cross bracing

8.8 Hurricane straps, wall plates and connections

8.9 Joint details for roof trusses

8.10 Asbestos-cement cladding (unfavourable in hurricane situations)

9 **Elements**

9.1 Structure

9.2 Architecture

9.3 Equipment

9.3.1 Electrical feed to be kept clear of roof structure

9.3.2 Electrical feed to be routed underground within the property

9.4 Contents

10 **Cost Considerations**

10.1 Capital costs ignoring natural hazards (hypothetical, academic)

10.2 Capital costs including natural hazards

10.3 Maintenance costs

11 **Analysis**

11.1 Understanding the structural model

11.2 Torsional effects

11.3 Geometric changes

11.3.1 The P-delta effect

11.4 3-D analysis (required only for irregular structures)

11.5 Dynamic analysis (required only for complex structures)

11.6 Stress concentrations

11.7 Complexity of earthquake effects and inadequacies of sophisticated analytical method

11.8 Effects of non-structural elements

11.8.1 Change in the natural period of the overall structure

11.8.2 Redistribution of lateral stiffness and, therefore, forces and stresses (this could lead to premature shear or pounding failures of the main structures and also excessive damage to the said non-structural elements due to shear or pounding)

11.9 Soil-structure interaction

11.9.1 Critical but usually ignored or played down

12 **Detailing**

12.1 Compression members

12.2 Beam-column joints

12.2.1 Reinforced concrete

12.2.2 Structural steel: - all-welded construction

12.3 Reinforced-concrete frames

12.4 Non-structural walls and partitions

12.5 Shelving

12.6 Mechanical and electrical plant and equipment

12.6.1 Securely fastened to the structure

12.6.2 Pipework

13 **Construction Quality**

14 **Maintenance**

14.1 Refer to Appendix A-XI – “Maintenance as a Tool for Mitigation”

EARTHQUAKES

CHECK LIST FOR NON-STRUCTURAL COMPONENTS FOR EARTHQUAKES

This Appendix constitutes a list of items and issues to be considered in designing the non-structural components of healthcare facilities to counteract the effects of earthquakes. Check lists are valuable as *aides-memoire* for the exercise. For any particular project all of the items may not be relevant, but excluding items from a comprehensive list is always easier than adding relevant items to a short list.

1 Electricity

1.1 Generator

- 1.1.1 Anchorage of the emergency generator

1.2 Batteries

- 1.2.1 Attachment of the batteries to the battery rack
- 1.2.2 Cross-bracing the rack in both directions
- 1.2.3 Battery rack bolted securely to a concrete pad

1.3 Diesel Fuel Tank

- 1.3.1 Attachment of the tank to the supports
- 1.3.2 Cross-bracing the tank supports in both directions
- 1.3.3 Bracing attached with anchor bolts to a concrete pad

1.4 Fuel Lines and Other Pipes

- 1.4.1 Lines and pipes attached with flexible connections
- 1.4.2 Able to accommodate relative movement across joints

1.5 Transformers, Controls, Switchgear

- 1.5.1 Items properly attached to the floor or wall

1.6 Bus Ducts and Cables

- 1.6.1 Able to distort at their connections to equipment without rupture
- 1.6.2 Able to accommodate relative movement across joints
- 1.6.3 Laterally braced

2 Fire Fighting

2.1 Smoke Detectors and Alarms

- 2.1.1 Properly mounted
- 2.1.2 Control system and fire doors securely anchored

2.2 Fire Extinguishers and Hose-reel Cabinets

- 2.2.1 Cabinets securely mounted
- 2.2.2 Extinguishers secured with quick- release straps
- 2.3 Emergency Water Tank
 - 2.3.1 Securely anchored to its supports
 - 2.3.2 Supports braced in both directions
 - 2.3.3 Supports of braces anchored to a concrete foundation
- 3 **Propane Tanks**
- 3.1 The Tank
 - 3.1.1 Securely anchored to its supports
 - 3.1.2 Supports braced in both directions
 - 3.1.3 Supports or braces anchored to a concrete foundation
- 3.2 Shut-off Valve
 - 3.2.1 System with an automatic, earthquake-triggered, shut-off valve
 - 3.2.2 Laterally braced
- 4 **Plumbing**
- 4.1 Water Heaters and Boilers
 - 4.1.1 Securely anchored to the floor or wall
 - 4.1.2 Gas line with a flexible connection to the heater or boiler to accommodate movement
- 4.2 Pumps
 - 4.2.1 Anchored or mounted on vibration isolation springs with seismic lateral restraints
- 4.3 Hot and Cold-water Pipes and Wastewater Pipes
 - 4.3.1 Pipes laterally braced at reasonable intervals
 - 4.3.2 Flexible connections to boilers and tanks
 - 4.3.3 Able to accommodate movement across joints
 - 4.3.4 Pipe penetrations through walls large enough for seismic movement
 - 4.3.5 Free of asbestos insulation (which can be broken in an earthquake)
- 4.4 Solar Panels
 - 4.4.1 Securely anchored to the roof
- 5 **Elevators**
- 5.1 Cab
 - 5.1.1 Properly attached to the guide rails
 - 5.1.2 Alarm system for emergencies
- 5.2 Cables, Counterweights, Rails
 - 5.2.1 Cables protected against misalignment during an earthquake
 - 5.2.1 Counterweights properly attached to guide rails
 - 5.2.3 Guide rails properly attached to the building structure

- 5.3 Motors and Control Cabinets
 - 5.3.1 Anchored

6 **Air Conditioning**

- 6.1 Chillers, Fans, Blowers, Filters, Air Compressors
 - 6.1.1 Anchored, or mounted on vibration isolation springs with seismic lateral restraints
- 6.2 Wall-mounted Units
 - 6.2.1 Securely mounted
- 6.3 Ducts
 - 6.3.1 Laterally braced
 - 6.3.2 Able to accommodate movement at locations where they cross separation joints
- 6.4 Diffusers
 - 6.4.1 Grills anchored to the ducts or to the ceiling grid or to the wall
 - 6.4.2 Hanging diffusers adequately supported

7 **Non-structural Walls and Partitions**

- 7.1 Concrete Block, Brick, Clay Block
 - 7.1.1 Reinforced vertically and/or horizontally
 - 7.1.2 Detailed to allow sliding at the top and movement at the sides
 - 7.1.3 Restrained at the top and the sides against falling
- 7.2 Stud-wall and other Lightweight Walls
 - 7.2.1 Partial-height partitions braced at their top edges
 - 7.2.2 If they support shelving of cabinets, securely attached to the structure of the building

8 **Ceiling and Lights**

- 8.1
 - 8.1.1 Suspended ceilings with diagonal bracing wires
 - 8.1.2 Plaster ceilings with the mesh of wood lath securely attached to the structure above
- 8.2 Lighting
 - 8.2.1 Light fixtures (*e.g.* lay-in fluorescent fixtures) with support independent of the ceiling Grid
 - 8.2.2 Pendant fixtures with safety restraints (*e.g.* cables) to limit sway
 - 8.2.3 Emergency lights mounted to prevent them falling off shelf supports

9 **Doors and Windows**

- 9.1 Doors
 - 9.1.1 If exit doors are heavy metal fire doors that might jam in an earthquake, provision of a Crowbar or sledge hammer readily available to facilitate emergency opening
 - 9.1.2 Automatic doors with manual overrides
 - 9.1.3 Directions in which the doors swing

- 9.2 Windows
 - 9.2.1 Glazing designed to accommodate lateral movement
 - 9.2.2 Large windows, door transoms and skylights with safety glass

10 **Appendages and Sundries**

- 10.1 Parapets, Veneer and Decoration
 - 10.1.1 Parapets reinforced and braced
 - 10.1.2 Veneers and decorative elements with positive anchorage to the building
- 10.2 Fences and Garden Walls
 - 10.2.1 Designed to resist lateral forces
 - 10.2.2 Masonry walls reinforced vertically and rigidly fixed to their bases
- 10.3 Signs and Sculptures
 - 10.3.1 Signs adequately anchored
 - 10.3.2 Heavy and/or tall sculptures anchored to prevent overturning
- 10.4 Clay and Concrete Roof Tiles
 - 10.4.1 Tiles secured to the roof with individual fixings for each tile

11 **Movable Equipment**

- 11.1 Communications
 - 11.1.1 Radio equipment restrained from sliding off shelves
 - 11.1.2 Telephones placed away from edges of desks and counters
 - 11.1.3 Elevated loud speakers and CCTV anchored to the structure
- 11.2 Computers
 - 11.2.1 Vital computer information backed up regularly and stored off site
 - 11.2.2 Heavy computer equipment of significant height relative to width anchored or braced
 - 11.2.3 Desktop items prevented from sliding off tables
 - 11.2.4 Access floors braced diagonally with seismically-certified pedestals
- 11.3 Storage of Records and Supplies
 - 11.3.1 Shelving units anchored to walls
 - 11.3.2 Shelves fitted with edge restraints of cords to prevent items from falling
 - 11.3.3 Heavier items located on the lower shelves
 - 11.3.4 Filing cabinet drawers latched securely
 - 11.3.5 Heavily-loaded racks braced in both directions
 - 11.3.6 Fragile valuable items restrained from tipping over
 - 11.3.7 Chemical supplies secured or stored in "egg crate" containers
- 11.4 Hazardous Items
 - 11.4.1 Gas cylinders tightly secured with chains at top and bottom (or otherwise)
 - 11.4.2 Chemicals stored in accordance with manufacturers recommendations
 - 11.4.3 Cabinets for hazardous materials given special attention with respect to anchoring

11.5 Furniture

11.5.1 Heavy potted plants restrained from falling or located away from beds

11.5.2 Beds and tables and equipment with wheels provided with locks or other restraints to Prevent them rolling unintentionally