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Preparing for the Worst: Developing Overhead Line Routes to Replace Damaged Cables

This paper discusses one aspect of the planning being undertaken by Wellington Electricity to prepare for a large earthquake disrupting one or more major 33kV cables in the Wellington CBD and surrounding areas. The planning includes developing conceptual emergency overhead line routes, and designing suitable poles & foundations, so the lines can be built in the shortest possible time with the least possible resource.

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1. Introduction

The events surrounding the Christchurch earthquakes revealed many engineering lessons for electricity network companies. One of these was the vulnerability of underground cables to rupture during earthquakes, and the value of being able to rapidly restore damaged cable routes with temporary overhead lines.

2. Background

The Wellington Electricity Network makes extensive use of 11 and 33kV underground cables, and being in a location with high earthquake risk is potentially exposed to significant earthquake cable damage, especially those cables of gas or oil filled construction.

To prepare for such an event Wellington Electricity, in consultation with Wellington City Council, has embarked on a project to proactively map out emergency overhead line routes which can be used to bypass damaged subtransmission feeder cables. This practice was undertaken by Mercury Energy in 1998 during the Auckland CBD crisis and also by Orion following the Canterbury Earthquakes.

Oil and gas filled subtransmission cables are sensitive to shock and harsh vibration, and in a number of cases in the Wellington CBD they pass over bridges or through tunnels which may become damaged due to earthquakes. Progressively the cables are being replaced with XLPE insulated cables as part of an on-going asset replacement programme, however in the event of a major disaster the time to locate and repair gas and oil cable faults, which could potentially be multiple faults per cable or circuit, would lead to prolonged outages lasting months.

Wellington Electricity is working with the Wellington City Council on levels of resilience and preparation for major events. By planning emergency overhead routes now and sharing this information with city planners, both parties understand what is required. It is expected that the City Council will approve these routes and protect the corridors to allow these lines to be constructed if ever required.

Upon completion of the Wellington CBD emergency overhead line routes, Wellington Electricity will continue the process with the other councils in its network area.

3. Establishing Emergency Routes

a) Concepts

In normal circumstances building new overhead lines through a densely populated urban area would require months or even years of detailed planning, contested resource consent hearings, consultation with possibly hundreds of land and building owners and consume a large budget. In Wellington City, new overhead construction is actually prohibited in the District Plan and so typically would not even be considered.

In a major emergency however where buildings have collapsed, streets are littered with rubble, major services such as water sewerage and electricity are severely disrupted or completely unavailable, the need to restore services becomes critical to the restoration effort.

Extreme circumstances will force normal planning processes to be suspended and emergency construction processes take over.

Therefore in these emergency situations it can become possible to build overhead lines in locations where normally it would never be considered. This includes across public parks, playing fields and other open spaces, over buildings, down the centres of roadways or along the sides of roadways where cars would normally park, removing trees where necessary, etc.

b) Routes Chosen

An examination of the 33kV cable routes on the Wellington Electricity network for criticality and vulnerability resulted in a short list of 10 key subtransmission feeders of gas and oil cable type, emerging from Transpower Grid Exit Points (GXPs) at Central Park and Wilton substations, supplying into the Wellington City area as shown in Table 1.

Table 1: Proposed Emergency Routes.

#	From Sub	To Sub	Existing Cable Route *	Length*
1	Central Park	University	Nairn, Willis, Aro, Adams, Fairlie.	1.8 km
2	Central Park	The Terrace	Thompson, Victoria, Able Smith, Terrace.	2.4 km
3	Central Park	Palm Grove	Wallace, Hanson Adelaide	2.8 km
4	Central Park	Hataitai	Hankey, Rugby, Mt Vic Tunnel	2.5 km
5	Hataitai	Evans Bay	Ruahine, Kupe, Evan Bay, Kemp.	2.5 km
6	Evans Bay	Ira Street	Cobham drive, Miramar Ave, Ira	2.5km
7	Central Park	Frederick St	Brooklyn, Billwill, Taranaki, Frederick	1.6 km
8	Wilton	Karori	Braithwaite, Curtis, Wilton, Churchill, Chartwell.	5.0 km
9	Wilton	Moore Street	Chartwell, Churchill, Blackridge, Wadestown, Park, Molesworth, Pipitea	4.2 km
10	Wilton	Waikowhai	Admiralty, Winston, Churchill, Waikowhai	1.8 km
			Total cable Length	**28.1km**

c) Preliminary Survey

To establish viable emergency line routes, preliminary planning was done using aerial photography followed by detailed on the ground inspections to determine potential problems and spot likely pole locations. The emergency routes use all available open space to achieve the most direct route and also the one which is least likely to encounter earthquake related obstructions such as slips, collapsed buildings or areas of liquefaction.

An example of a proposed emergency route from Central Park GXP to Wellington Electricity Hataitai substation is shown in **Appendicies A and B**. Of note is that the route uses public green spaces, car parks, crosses the Basin Reserve, and also uses several school playgrounds.

d) Post Survey Detailing

Once each tentative route is established, it is modelled in PLSCAD over a LIDAR terrain model to check ground clearances, determine structure loads and allocate foundation types. Pole locations are then refined, additional structures added or removed as necessary, and the design is finalised.

e) Drawings Package

Once the design is completed a set of drawings are produced including

i. The route as a route plan.
ii. The route as a profile with the pole types and foundations used at each location.

iii. A full material list for each line .
iv. A construction schedule with notes on aspects of the route such as tree cutting, special foundations, wiring guide etc.
v. A drawing of each standard structure type used is also produced (see Section 4)

The idea is that with access to packs of prints (one pack per line route), the line crews should be able to go to site and construct the line without further need to call for any other drawings.

4. Poles Crossarms, Insulation and Conductors

a) Concepts

At the outset of the project it was decided that rather than create a set of specialist emergency structures, the lines would make use of normal line components and conductors. The advantages of this approach were-

i. All parts would be familiar to line crews.
ii. Erection tools and techniques already exist and are well shaken down
iii. All parts would be regular stock items and purchased at normal bulk prices
iv. Emergency stock holding would be rotated with normal project stock to reduce deterioration and obsolescence.
v. Less overall stock would need to be carried reducing inventory levels and storage related costs.

b) Poles

All normal pole types were catered for (timber, concrete, steel) so as to be able to use whatever is available at the time, but the nominal “standard pole” type is the Busck prestressed concrete B12.4 high strength pole of 12.4m overall length and 43kN top load.

c) Crossarms and Insulators

Conventional hardwood crossarms with composite post and long rod strain insulators are used. Conductors are arranged in a horizontal single circuit, but with a triple crossarm vertical double circuit option available if required.

d) Conductor

A number of specialist conductor types were considered for the project, but as noted above it was decided to utilise a single standard conductor already in wide use on the network. This also meant that joints and terminations would be standard stock items and readily available.

The conductor chosen was AAC Cricket (16.1mm dia). This conductor can deliver 25MVA at 33kV and so was adequate to replace any of the nominated cable routes given in Table 1, especially considering that load would very likely be well below normal peak levels due to damage to consumer’s premises.

e) Standard Structures

The line components were built into a range of “standard” pole structures which are used throughout the emergency line designs. Each structure has a drawing with a materials list. The line route plans therefore note which standard structure is used at each location, and one drawing of each is included in each line drawing package.

5. Pole Foundation Options

a) Concepts

Building lines in locations such as parks and urban streets conventional direct embedment foundations can be used without significant problems. These are simple to construct, cheap and reliable. Where the lines take direction changes, staying back to buildings, trees, direct embedment or screw anchors can be used. Stays can even be anchored to lengths of timber or metal embedded in piles of rubble.

However building lines in an emergency along busy urban streets including congested CBD locations such as The Terrace, presents unique foundation challenges including the time required to excavate through extensive underground services, digging through concrete and hard paving, potential damage to services under the roads etc. It was decided that a special surface mount foundation is required to deal with these locations.

b) Surface Mount Foundations

The design criteria for the surface mount foundation included

i. Suitable for concrete, timber and steel poles.
ii. Readily transportable and installable without specialist tooling or machinery
iii. Collapsible for storage
iv. Suitable for sloping sites
v. No excavation required.
vi. Load capacity of the order of 380kN/m.
vii. Recoverable and reusable indefinitely.

To meet these objectives a steel framed design was developed, held down with 1m x 1m concrete anchor blocks. To achieve full overturning capacity up to 8 blocks can be used but a lesser number are required where the full capacity is not required. (Most sites)

The pole butt and “ground line” clamps are adjustable to fit most pole types and sizes. The strut supports are adjustable for length to allow for sloping ground, and can be disconnected and laid down for transport and storage.

A preliminary sketch of the foundation is shown in **Figure 1.**

Detailed stress modelling on the design is being carried out as this paper is being written, and this will likely result in further changes to the design. Following detailing a prototype will be built to prove the foundation in a full scale mechanical test, before the design is approved for production.

A complementary stay (guy) anchor sled has also been designed for locations where there is no other available option to anchor a pole stay. This consists of a steel frame capable of mounting up to 2 concrete anchor blocks. The proposed design is shown in **Figure 2**

In locations with very high anchor loads, two or more sleds can be used together.

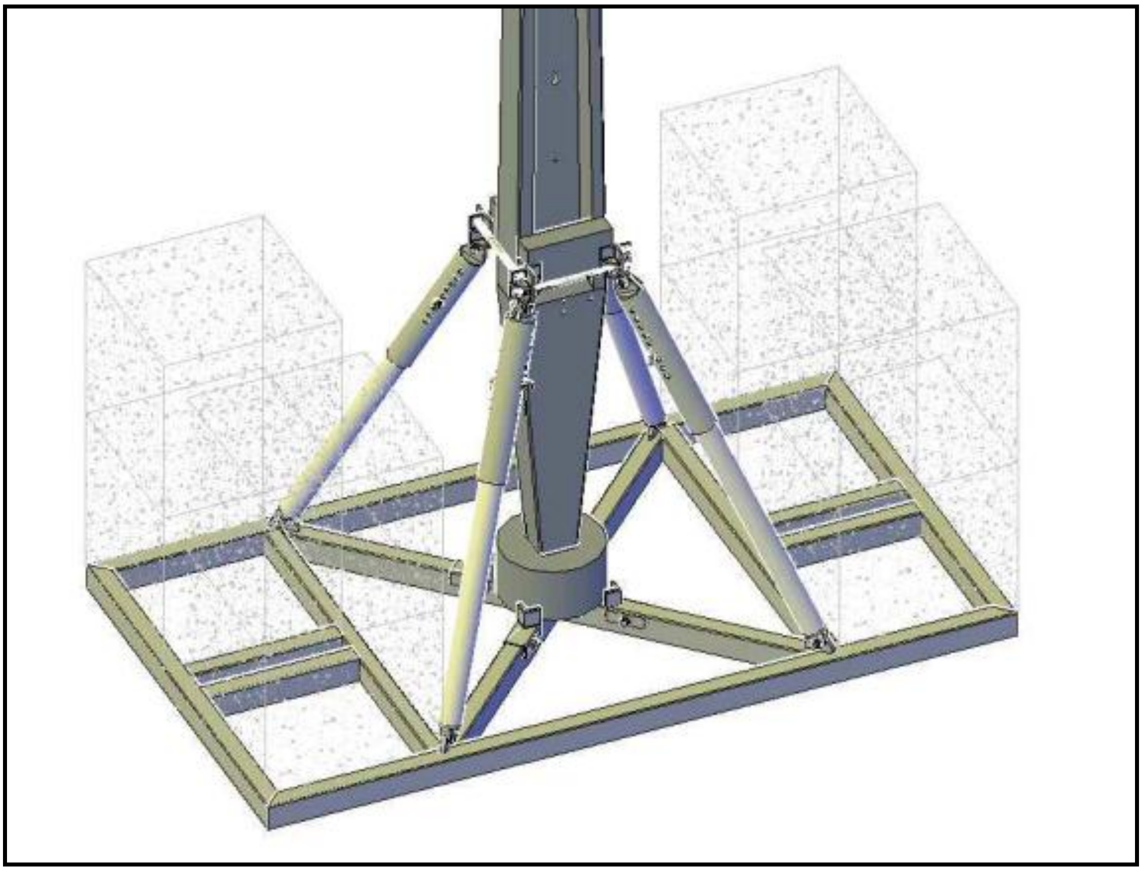

Figure 1: Surface Mount pole foundation design

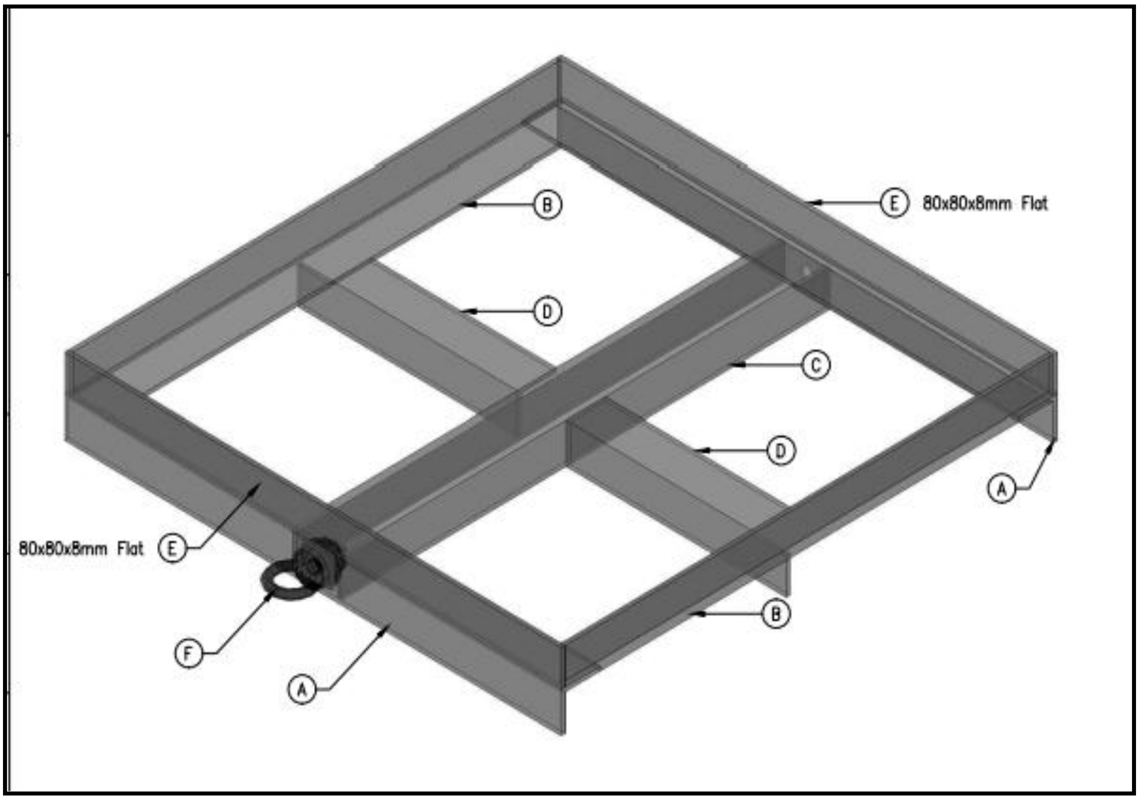

Figure 2: Surface Mount Stay Foundation Sled design

6. Connecting into Substations

a) Introduction

Where the existing connections into a substation are cabled, (as they mostly are in this case) connecting in overhead circuits presents special challenges.

b) Transpower Substations

Examination of the two Transpower substation 33kV feeder connection arrangements showed that the majority of these were accessible via the cable pot head connections on outdoor structures. (All at Wilton, most at Central Park). These cable connections therefore present no major difficulties connecting to an overhead line.

b) Wellington Electricity Substations

The Wellington Electricity substations however .present unique connection challenges as all are fully enclosed substations with no outdoor structures or roof bushings.

Connection methods for these substations are yet to be considered in detail, but the options for each may include

i. Cutting into the existing cable where it exits the substation (or at any other suitable location along the route), installing a set of cable end terminations and bushings, and mounting them on a pole or other suitable structure such as a building wall or roof. This option has particular challenges for gas and oil filled cables.
ii. Making up temporary internal to out-door connection from XPLE cables. On the indoor end the cables would connect via a circuit breaker to the bus, then be run along the floor or walls of the sub to a suitable outdoor location, where external composite bushings would connect to the overhead line. The cable end bushings could be mounted on a pole or on a bracket bolted to the substation wall or roof.
iii. Permanently modifying the sub to provide an additional bay, connected to permanent outdoor wall or roof bushings.

Each option has advantages and disadvantages for any particular substation, and so a one size fits all approach is not likely to be viable.

7. Materials Management

a) Concepts

Wellington City is unique in being particularly vulnerable to becoming isolated from the rest of the country during a major earthquake, due to major slips / landslides etc severing road and rail connections to the north. It is also far from certain that the airport and port infrastructure would remain usable. The time required to fully restore these transport connections could be of the order of weeks, leaving only heavy lift helicopter and perhaps sea connections available during that initial period.

The effect of this scenario is that much of the emergency lines restoration may have to be undertaken using local material supplies, leading to a situation where a greater level of stock holding is necessary than would normally be the case.

b) Approach

With the city cut off from access to significant supplies of new poles, crossarms, conductor, insulators and other new line materials, emergency lines may have to be largely built with existing stock. There will also be a need to restore other damaged parts of the overhead network leading to a critical drawdown of locally stocked materials.

Moderating the materials demands will be the fact that the local roading network may be significantly damaged, fuel supplies for vehicles restricted, access to linemen, trucks and equipment may also be significantly constrained.

The proposed approach is to always hold in stock adequate materials so as to be able to build the longest emergency line, plus an allocation of materials for other general repairs. This minimum stock level will be rotated with materials for on-going work, thus eliminating unnecessary stock deterioration.

The expectation is that once all these materials are consumed in an emergency, road and/or rail and/or sea/port connections will have been restored sufficiently for additional materials to be brought in as required.

8. Line Construction Issues

Construction of the proposed emergency line designs requires no special training, tooling equipment or techniques not already available and in daily use by Wellington Electricity staff and their contractors. It also means that should emergency crews be brought in from around NZ to speed restoration, they will not be faced with unfamiliar materials or repair tasks.

Each emergency line route will be supplied with the construction drawing package noted earlier listing the pole type, and foundations required at each location, plus comments on any trees needing to be cut or other construction issues such as lines needing to be over-wired and protected etc.

9. Summary

Wellington Electricity is attempting to proactively plan for cable failures during a major earthquake in the capital city. Emergency overhead line routes are being developed which utilize available public open spaces so as to get the lines up in the quickest possible time. Special surface mount foundations are being developed for major city streets eliminating the need to excavate to install poles. Stock holding of line materials such as poles crossarms, conductors, insulators and joints is to be increased, as it is possible that supplies will be constrained for some weeks after a major earthquake.

Appendix A: Proposed Central Park to Hataitai Emergency Line Route: Part 1

Appendix B: Proposed Central Park to Hataitai Emergency Line Route: Part 2