Effects of the Newcastle Earthquake of 1989 on the New South Wales High Voltage Transmission System

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Summary

The Newcastle earthquake of 1989 had a significant effect on the high voltage transmission assets of the NSW electricity supply grid operated by the Electricity Commission of NSW. Multiple failures of equipment, mainly switchgear, occurred in a number of the electricity substations closest to the earthquake epicentre. These failures initiated a general and immediate shut-down of electricity supply to both industrial and domestic consumers in the affected area.

The response of the Commission to this unexpected emergency was immediate and effective. Operational recovery saw high voltage supply restored to major industrial customers 1½ hours after the incident. Restoration of supply for general distribution began within 30 minutes, with all bulk supply points energised after 2½ hours.

Of course, the damage then had to be assessed, plant safety assured and repairs commenced so that normal levels of reliability could be returned to the community. This phase of restoration took 3 weeks to repair most major circuits and many months to complete. In the latter stages, it was accompanied by a third phase of review which identified any areas where either the system design or the response of a power authority to any future such emergency may be improved.

The paper begins with the showing of a staff video prepared after the earthquake. It shows elements of the damage and summarises the Commission's response in the emergency phase of recovery. The speaker will then summarise some of the more significant lessons learned in the three phases of response.

Keywords: earthquake, electricity, supply, power, transmission, design, switchgear

1. INTRODUCTION

1.1 NSW Power System. In December 1989, responsibility for the generation and bulk supply of electricity across NSW still laid with a unitary State government authority; the Electricity Commission of New South Wales (ECNSW). The Commission had been formed in 1952 to amalgamate the generation and network elements of a number of separate authorities for efficiency and integrated planning for growth. By 1989 it had developed a strong and reliable state-wide network with interconnection to Victoria and a right to 75% of hydro power from the Snowy Scheme. This hydro resource was also important for controlling stability of the integrated east coast system, which by then extended for a length of approx. 2,200 km.

1.2 Power Generation. New South Wales has been blessed with vast reserves of quality coal suitable for conventional steam power generation. From 1958 base load power stations were developed on the coal fields. A high voltage backbone of 330 kV transmission lines (with a single 500 kV line) provided transmission capacity to major load centres around Sydney and its industrial satellites, Newcastle and Wollongong and the southern interconnection. A sketch of the main grid system of the NSW system in 1989 is shown in Fig. 1.

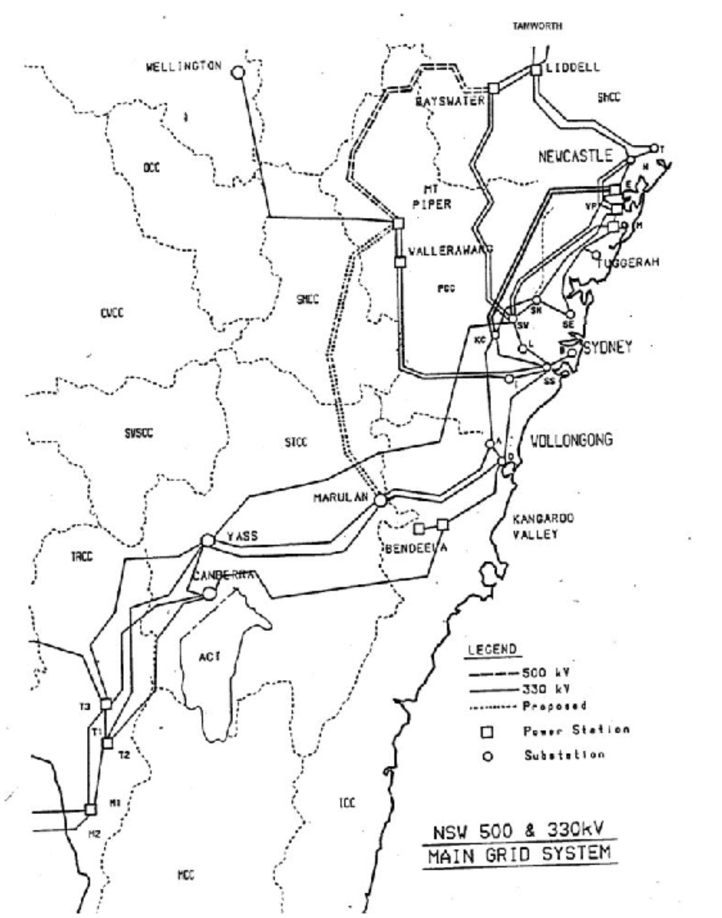

Figure 1: NSW 500 and 330 kV Main Grid System (Benyon 1989)

1.3 Glossary.

HV: High Voltage,
SS: Sub-Station,
PS: Power Station,
CB: Circuit Breaker,
NSW: New South Wales,
BB: Bus Bar, a solid connector,
kV: kilovolt, a measure of voltage,
MW: Megawatts, a measure of power,
Hz: Hertz, a measure of frequency,
DEO: District Electrical Operator,
DAC: Data Acquisition and Control system.

2. THE NEWCASTLE EARTHQUAKE, 28TH DECEMBER 1989

The NSW Power System was operating normally on the morning of the 28th December 1989, delivering a state system load of 5625 MW. Being in the middle of the Xmas/New Year holidays, major outages of plant were not scheduled, affecting availability, but staff resources were reduced by some taking leave.

When the earthquake hit Newcastle and surrounding areas at 10:29 am, no one was more surprised than staff of the Electricity Commission, most of whom had never even felt a minor earth tremor before, or anticipated that a major quake of scale 5.6 on the Richter scale would devastate their world on such a fine day in a season of good cheer:

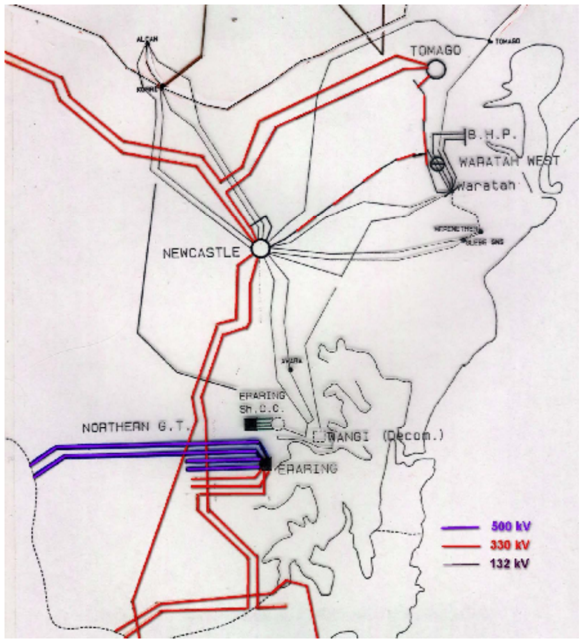

Figure 2: Newcastle Area Map (ECNSW, 1989)

3. EFFECTS OF THE EARTHQUAKE ON THE NSW POWER SYSYEM

The epicentre of the Newcastle earthquake was placed near Boolaroo (32.95° S, 151.61° E) (McCue et al, 1990). The key elements of the NSW HV system affected were the substations in the immediate vicinity, particularly Newcastle 330/132 kV SS located near Killingworth, only 6 km from the epicentre. The Waratah 132/33 kV SS was also badly shocked along with the nearby Newcastle Area Control Centre, 11.5 km from the epicentre.

3.1 Transformer Trips. The initial consequence of the tremors impacting the NSW system was an almost-instantaneous disconnection (trip) of some of the severely shaken transformers at network sites. These widespread trips were an unplanned occurrence, caused by sloshing of the sensitive mercury switches in “Bucholz” relays (protection devices which are fitted to detect oil surges indicating serious internal faults, see figures 3 & 4).

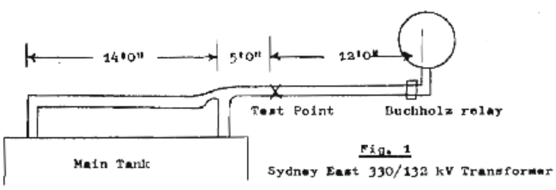

Figure 3: Sketch of the location of a ‘Bucholz’ relay on a 330/132 kV transformer tank.

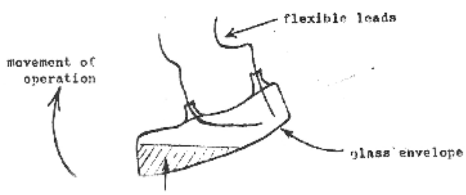

Figure 4: Sketch of the mercury switch and contacts in a ‘Bucholz’ relay.

3.2 Disconnection and Load Drop. Customer loads supplied through these transformers were disconnected and the system load was suddenly reduced. Severe load changes to long systems may cause instability; however, the effect of this change on the network was ameliorated by the trip of a (200 MW) generator at Munmorah SS. This trip was suspected to also be a result of false 'Bucholz' operation. The overall loss of approx 900 MW (approx. 16% of state load) caused the system frequency to rise to 50.37 Hz within 2 seconds, but frequency stabilised and returned to 50 Hz after some minutes.

3.3 Customer Interruptions. Three pot lines operating at the Alcan aluminium smelter were lost, a total of 280 MW. The Tomago Smelter was unaffected as it remained supplied by a 330 kV transmission directly from the Liddell Power Station Switchyard. About 470 MW of distributor load was lost in the northern region, mainly Shortland Electricity. Sydney County Council lost 100 MW and Prospect 50 MW.

3.4 Failure of Porcelain Insulators. Porcelain is familiarly used for insulation of high voltage apparatus. It has superior insulation, durability, corrosion and certain strength qualities. But it is well known to be a brittle substance and sensitive therefore, to shock. HV equipment in outdoor substations uses solid or hollow porcelain insulators for support, conveying motion, or containment of operating parts. In substations closest to the epicentre, porcelain breakages were the source of most primary damage.

Figure 5: Failure of a single interrupter pole on a 330 kV circuit breaker at Newcastle 330/132 kV SS.

3.5 Primary Equipment Damage. As a result of porcelain insulator failures, the earthquake critically damaged ten 132kV CBs (high current switches), although most failures involved only one phase. Due to the prior tripping of the transformers, few of the initial insulator breakages resulted in severe electrical faults, but hazardous conditions were set up. Figure 5 shows a (single pole) failure on a 330 kV CB at Newcastle Substation.

3.6 Consequential Mechanical Damage. The collapse of primary components (mostly heavy interrupters, or air tanks) often caused consequential damage to adjacent circuit elements. These were mainly HV isolators, (low current disconnectors), current transformers, or conductor insulators. This consequential damage may be caused by shock loads transferred to these elements by tight conductors or by fragments from exploding porcelain components.

3.7 Other Effects. The collapse of CB poles also initiated a series of leaks in the compressed air systems used to operate the breakers. Tripping of sections of the 330 kV busbars (one of four) and 132 kV busbar (two of four) after the main shock occurred at Newcastle Substation due to electrical faults at the equipment with failed porcelain insulators.

3.8 Interconnector Performance. Important to the integrity of the transmission system, there were no permanent failures of its transmission lines or underground cables. Only one trip of a 330 kV circuit occurred (No. 93 Eraring), possibly as a result of conductor clashing.

3.9 Remote System Trippings. Less severe consequences of the earthquake were felt widely across the high voltage system: A generator tripped at Munmorah Power Station, approximately 30 km from the epicentre. Both 330/132 kV tie transformers at Vales Point Switchyard (24 km), both 330/33 kV station transformers at Munmorah (30 km) and both 132/33 kV transformers at Eraring Switchyard (15 km) tripped, also due to Bucholz relays. These trippings caused no consequential damage.

3.10 Ancillary Effects. Some significant structural damage to buildings and walls occurred at system substations, but this was not critical.

3.11 Effects on Distributors. Similar effects on electricity distributors in the affected areas were noted. About 70 transformers tripped, but damaged equipment due to porcelain failure was not so evident, as the lower voltage insulators are much smaller and were not subjected to high stress levels. Shortland County Council evacuated their city building and control centre for a short time due to some structural damage.

4. RESTORATION OF SUPPLY

4.1 Understanding the Disaster. The second shock affecting local staff after the main tremors subsided was in comprehending the extent of the earthquake effects. At first the affected area was completely unknown. Was the blackout state-wide as some imagined? Was the damage this bad elsewhere? Fortunately, quick contact was made with other system centres through the emergency operational facilities, only to find that Newcastle was the major system area affected. The realisation that they were the only region facing a completely unexpected disaster of unknown consequences suddenly struck home to Newcastle Area staff.

4.2 Emergency Precautions and Procedures are Vital. The key elements to a fast and effective restoration of supply were the collection of data, understanding what had

happened and having resources available to initiate safety and restorative actions. The ECNSW had a policy of 24 hour manning of its main control centres with System Operators. One of these centres was in Newcastle and, fortunately, had been able to remain operating with its planned emergency power and communications systems, even though the public services failed. Safety and switching action in the field was carried out by District Electrical Operators, also on a shift basis. As the event occurred in normal working time, maintenance staff were able to be re-assigned to assist in the wide range of tasks, ensure security and prepare for repairs that were immediately required at affected sites. Many of the staff on leave made contact, offering their services. In the large part, these offers were gladly accepted.
An emergency command and contact centre was quickly put into action at the Newcastle Area offices in Waratah. Fortunately, adequate engineering and supervisory staff were quick to respond. The high voltage testing section of the ECNSW was given early warning of the need for a range of testing to be carried out and asked to send teams to the area. Control staff followed restoration procedures that had been part of their training and had been proven in minor emergency situations, such as individual plant failures. A network-wide oversight and monitoring of system performance & capabilities was provided by the State Control Centre in Sydney.

4.3 Assessment, Security and Safety Actions. At the time of the earthquake, it was most fortunate that two of the DEOs were working at the worst affected location; Newcastle 330/132 kV SS. They were able to assist in the key elements of restoration with minimal delay. Their first actions were ensuring safety and then the isolation and preservation of compressed air supplies on which all the main switchgear relied for its safe operation.

4.4 Collection of Data. ECNSW had recently installed a Data Acquisition and Control (DAC) system across the power system for the automation of data management tasks and the performance of certain switching operations. At first the DAC system returned some confusing indications to the control centre about the status of plant, due to the overwhelming number of events (approx. 250) that were signalled to it during the first seconds. The DEOs were quickly able to assist in confirming the status of indications on site; enabling the valuable DAC system to be reset where necessary and relied upon.

4.5 Transmission Circuit Checks. As a number of lines had tripped and their status was unknown, ground and helicopter patrols were called into action. These later reported no permanent damage to aerial circuits. Assessing the condition of underground circuits was less clear. As there had been no previous earthquake experience in this area, a pre-conceived image of violent earthquake effects noted overseas, particularly in the well-publicised California quakes, led to expectations of violent ground shear effects damaging buried cables. So the return to service of the one, major 132 kV cable in the area (No.9N9) was delayed until a better picture of the quake effects was available. But to be sure, critical tests of the cable’s insulating oil pressure and electrical condition were initiated.

4.6 Customer Coordination. Contact was quickly made with customers, both distribution authorities and industrial customers supplied directly. Reassurance was given that the power system disturbance, whilst severe, was only local and that there was no general shut-down threatening long term supplies. Arrangements were made for communication, coordination and if required, avenues for providing mutual assistance. Priority was given to the restoration of supplies to the Alcan smelter, to BHP to avoid costly plant damage, and to Newcastle city, in the anticipation that supply safely restored may assist in rescue and emergency activities.

4.7 Progressive Restoration by Distribution Authorities. Restoration of supply by Councils was begun only in areas outlying Newcastle as soon as it was clear there was no local damage. The majority of supply areas other than those close to Newcastle were restored within one hour. Restorations to Sydney & Central Coast area loads were completed within one hour. North coast supplies were progressively restored within ½ to 3 hours.

4.8 Restoration of Supply from Newcastle SS. Restoration of supplies from this critical point of supply was difficult and risky. Delays had occurred as damaged equipment needed to be removed and air supplies rebuilt. The main effort was concentrated on energising the 330/132 kV transformers and then sections of the 132 kV bus. Two transformers were energised after 21 minutes from the quake, but as both 132 kV bus-section CBs had failed, extra disconnections and checks were required before one 132 kV bus was restored after 1 hr 48 minutes.

4.9 Restoration of Local Bulk Supply Points. Supplies to Merewether and Tomago were restored in close to two hours, thus permitting most of the eastern and central parts of the Newcastle city area, and areas north of the Hunter River to be restored. Waratah was re-energised after 2 hours and all feeders closed by 2½ hours. About 80% of load was restored within 3½ hours. (Shortland C.C. chose to avoid restoring supplies into the heavily damaged areas of the city due to safety concerns.)

4.10 Direct Industrial Customers. Supply to all 3 Alcan potlines was restored within 2 hours 41 minutes. (Only one pot (ce11) out of 360 was reported damaged.) Supply to the BHP works was restored after 2 hours 12 minutes. Both Companies reported little other damage and expressed appreciation for the manner in which restoration by the Commission was handled.

5. REPAIR OF DAMAGED PLANT & SERVICES

5.1 Plant and Inventory Assessment. Immediately after the earthquake, maintenance staff who were not assisting in the restoration of supply were sent to affected Substations to gather information on the plant that was damaged and to prepare for its disconnection from the system. Inventories were made of both the spare plant that was available, as well as assessments of redundant, or little-used equipment bays that may be utilised for replacement parts.

5.2 Organisation for Repair Works. A dedicated (full time) coordination team was set up to plan and direct the detailed repair and recovery work. It was headed by a senior engineer with experience in the commissioning of electrical plant, and included representatives from all field groups, including the asset maintenance, technical services and system operation sections. Other specialist advisers, such the electrical testing group, were asked to contribute as necessary. Initially the team met daily to schedule the program of works, using all available aids. In the first two weeks or so of the restoration the team operated directly from the damaged field locations.

5.3 Resources for Repairs. Staff resources from other state areas were kindly sent to Newcastle to augment specialist maintenance groups during the emergency period. Teams arrived from many of the other eight Transmission areas to assist. Leave-takers continued to call in offering their services, others responded to calls for assistance. Repair operations were carried on over weekends and often into the night to take advantages of operational windows and to speed the return of adequate levels of supply reliability to sensitive areas. The response by staff at all levels during the whole recovery phase was outstanding.

5.4 Issues Faced in Emergency Repair Phase. A summary of the special issues faced during the repair phase is listed below: (For more information on these issues, refer to the references noted.)

- **Safety**. Staff safety was a priority issue. The level of safety awareness required near high voltage apparatus is very high under normal circumstances. But working amongst such apparatus that had the potential for being damaged, required continual review of safety issues, identifying any know hazards, anticipating new threats and devising means to protect staff and services to those threats. An ECNSW registered nurse was stationed at Newcastle SS for the critical restoration period. It is a great tribute to the staff and support groups involved, that apart from some cuts to hands received in the early phases of handling broken porcelain, there was no significant injury.
- **Porcelain Failure**. The most outstanding example of new safety issues was the potential for failure of cracked or stressed porcelain components in insulators and support columns. Some cracks cannot be seen, even under close scrutiny. Calamitous failure of some circuit breaker porcelains in early restorative switching made this danger very clear to staff. It became standard practice to vacate switchyard areas during the initial switching of major apparatus, even if electrical tests had been carried out and other operating safety precautions were instituted.
- **Porcelain Testing**. More permanent assurance was established by the identification of cracks in porcelain components. This was done during de-energisation, by the application of a proprietary dye onto the insulator surface, after a soak time the surface dye is wiped away with clear solvent, and then a chalk-like foam is sprayed onto the porcelain surface. The fine dye solution is absorbed

Figure 3: Fitter applies dye to the chipped porcelain insulator of a 330 kV current transformer.

into any crack but will be drawn out into the chalk coating as it dries, to show up as a clear dye-line. Maintenance staff regained confidence and became very skilled with this little marvel. (see Figure 3) De-energised bays were routinely checked, even if no damage was visually evident in that bay.

- **Replacement Parts.** The sheer scale of damage resulting in shortages of spare parts for faulty equipment, particularly major CBs, frustrated repair efforts. In some bays this necessitated their complete replacement with new CBs, requiring new foundations and replacement of all three phases regardless of the damage. Sometimes replacements units of lower rating were utilised, with fully rated replacement units being re-scheduled for a later date. Other Areas and Power Stations assisted in the search for and provision of spare parts.
- **Connected Equipment**. Consequential damage to isolators, current transformers and insulators from the collapse of heavy CB poles created shortages of these components, as well. In their restoration, more slack was given to the HV connectors where possible to prevent recurrence of this effect (see section 6.5).
- **Bucholz Relays**. Whilst being responsible for the unplanned, system-wide transformer trips, Bucholz relays can be modified to correct their seismic instability. The mercury switches can be replaced by an improved design of reed relay that performs much better under seismic disturbances. An urgent program was immediately initiated to replace the mercury switches, starting at main system transformers and other priority supply points across the network.

5.5 Progress and Scale Of Works. As an indication of the scale of the repair works, after two months works at the Newcastle SS alone involved:

- major repairs to damaged plant at three 330 kV bays and eight 132kV bays,
- investigative testing on all five major transformers (particularly the porcelain bushings) and their switch bays,
- investigative testing on three other 330 kV switch bays and four 132 kV bays.
- Note that dye tests to that date had identified porcelain insulators in three other switch bays as being cracked and therefore requiring replacement.

At Waratah SS, four of the thirteen 132 kV CBs had failed and faulty insulators were being replaced in seven other units; one failing explosively during energisation. At Merewether SS, one cracked support insulator was found and replaced on a 132 kV CB.

6. ANALYSIS AND LONG-TERM REVIEW

6.1 Analysis of Main Features of the Earthquake Effects. The nature and extent of the damage to the NSW power system by the Newcastle Earthquake was clearly outside any previous experience in Australian conditions. This had a longer term effect on the management of the system, demanding inquiries into why it happened; can it be expected again, in Newcastle, or elsewhere; and how to prepare the power system for future seismic risks.

Two elements of the incident are critical in any analysis of the effect of the earthquake on the NSW power system. One of these was the almost instantaneous tripping of transformers due to Bucholz relay operation, which dropped about 16% of the state load at the time. The other was the widespread failure of porcelain insulators, particularly on the tall, higher voltage plant.

6.2 Bucholz Relay Operations. In addressing the Bucholz actions first, there are both bad and good elements to the unplanned nature of these trippings. While they initiated the wide-spread power loss seen, they may have protected more severe damage occurring in the system. In particular, the incidence of major electrical faults on the system, the likelihood of electrical faults in lower voltage networks, or even dangerous electrical conditions in customer equipment and wiring damaged by the earthquake was minimised.

Electrical faults on the main system are, fortunately, infrequently experienced except on transmission lines as a result of lightning, or possibly bushfires. If one occurs on a high voltage substation busbar, it can be very severe, as the fault will be fed from multiple lines or sources. And especially if it is not correctly interrupted, the effects of the fault can have serious consequences, as follows:

- Damage to main system transformers may occur if a "through fault" occurs on a substation busbar and is not interrupted within a short time period due to defective CBs. Main system transformers are the most critical and sensitive elements of the power system, as they are insulated by large amounts of oil and require sensitive protection devices (e.g. the Bucholz relay is one). Transformers are also the most time-consuming and expensive elements to replace.
- System stability, ie maintaining the frequency at which the system operates (50 Hz) and at which all synchronous machines must rotate, is a necessary measure of a power system's operating performance. This is particularly important on a long system with main loads remote from main sources of generation. Stability can be threatened when a major fault occurs, changing voltage levels and system frequencies in parts of the system. If not quickly balanced, the system may become unstable with rotating machinery spinning at different speeds. This will lead to more extreme events such as system splitting, or load shedding in other locations. The social consequences of system shut-downs are well illustrated by the New York blackouts of 1965, 1977 and 2003.

6.3 Porcelain Insulator Failures. The breakages of the porcelain insulators are a totally undesirable effect. However, their effects could have been much worse, because during the Newcastle earthquake there was no major, lasting fault that could cause either of the serious consequences mentioned in the paragraph above. There may have been, if the Bucholz trippings had not happened initially. This is because the porcelain breakages in the switchyard causing circuit breakers to fail and topple over happened some seconds after the Bucholz trippings had occurred. The conductors were therefore de-energised or fed only by a low power source when they fell. So major short-circuits of the kind feared by system managers could not occur.

6.4 Committee of Review. A formal 'Committee of Review' was established by the Commission on the day following the earthquake. Its brief covered a wide range of issues that affected the performance of the system during the earthquake. The Report was completed and issued two months later, carrying 35 recommendations for specific action, or for further investigation. (Committee of Review, 1990)

It was the Committee's view that any such future earthquake could be withstood with fewer problems and with less damage or disruption if certain key actions were taken. These actions will be based on USA and New Zealand experience, showing that costeffective improvements are possible (e.g. NZE, 1975). They will be aimed to reduce the extent and severity of disruption and damage in the event of a similar incident elsewhere on the system. This refers in particular to the minimisation of circuit breaker failures (Benyon 1990, p 3). Several of the Review's more significant findings were:

- **Transformer Relays**. A programme of fitting seismic-resistant Bucholz relays to main transformers is to be urgently completed across the NSW system.
- **System Design for Emergency**. The ability of the Commission to quickly and effectively recovery from this emergency confirmed the soundness of its astute planning practices designed for emergency and flexibility. Critical supply elements within substations are duplicated and supply circuits for major loads are duplicated; each being fed from an alternative busbar or source (for example, the Tomago Smelter remained supplied from Liddell PS). These reliability measures allowed supply to be restored as soon as faulty plant could be cut away, isolated, and plant safety assured.
- **Plant Design for Seismic Risk**. The poor performance of some substation equipment, particularly long porcelain insulators supporting heavy loads, under earthquake conditions required an assessment of seismic susceptibility across the system. International design experience showed that resilient mountings, additional bracing of structures, avoidance of resonance, and attention to the damping of vibrations in plant will improve performance.
- **Site Precautions**. The Committee found that site selection and design are also critical, as a site on high strength sub-soil will minimise the damaging acceleration forces on structures when tremors hit. A task force was established to look into these latter two matters.
- **Communications and Control**. Although it performed without fault, a review of the Data Acquisition and Control system was recommended to improve the indication of emergency system conditions necessary to determine subsequent operating actions. In the same way, telephone and operator facilities at control centres and switchyard sites were to be upgraded for coping with emergency communication requirements.

6.5 Substation Design. The task force recommended for analysis of plant and site matters was quickly established and delivered a report in August 1990 (T.P.E. 1990). Some of the more interesting findings address the dynamics of structure designs during seismic events:

- **Seismic Standards**. Built in 1969, the design criteria at Newcastle SS and other switchyards had not been strengthened in expectation of major seismic events. Structures and buildings were built appropriately for Newcastle, in accordance with Zone 1 requirements of AS 2121 (1979), which applies to about 80% of Australia. However, in response to the possibility that such random events may occur elsewhere, the task force concluded that: "*All (switchyard) structures should be designed with an appreciation that they could be required to resist an earthquake*" (T.P.E. 1990). In future, the practice of designing for a superior seismic performance relative to the seismic risk zone anticipated at any site would be adopted.

- **Ground Conditions**. The site of Newcastle SS Switchyard had been constructed by the ‘cut and fill’ method. The dividing line between cut and fill ran across the main switchyard, see Figure 4.

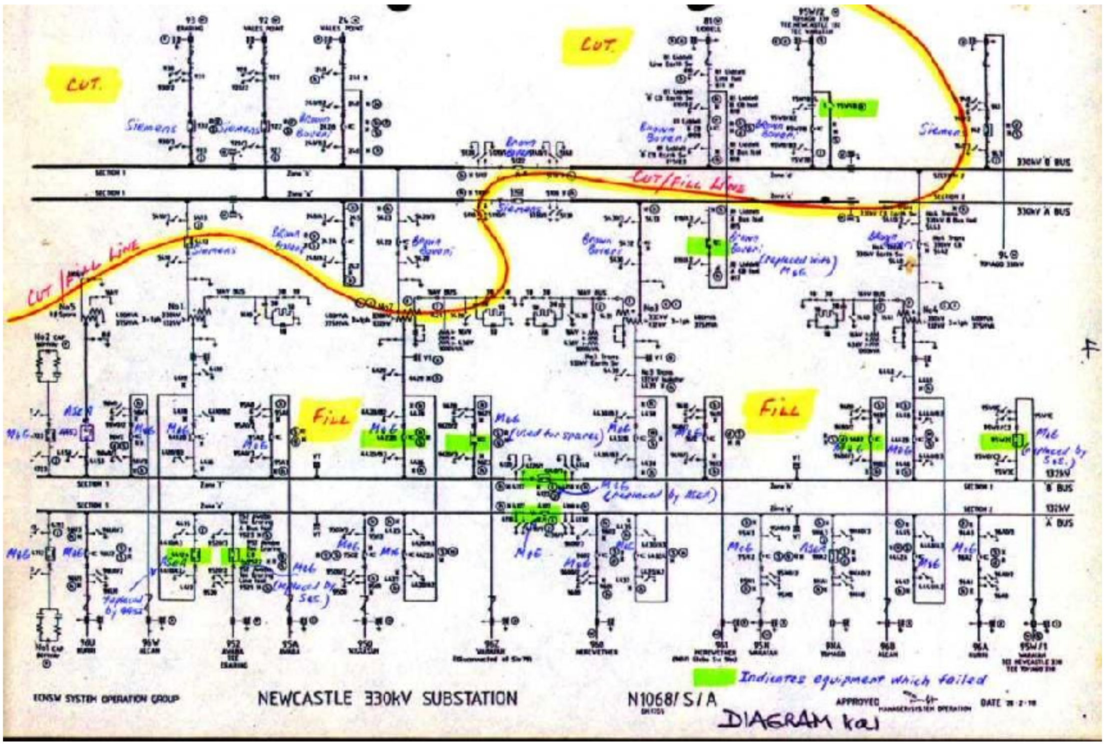

Figure 4: Newcastle 330 kV SS layout. Damaged circuit breakers are shown marked green. The ‘*cut/fill line*’ shows the dividing line between the two switchyard ground conditions.

The task force found that there was a very good correlation between different ground conditions and the extent of damage to plant suffering porcelain insulator damage. This finding agreed with most of the earthquake effects seen in the larger community: Infrastructure located on fill, sand, or soil of unstable nature suffered more damage than on a high strength bench, or solid rock. Unstable footings can amplify the dynamic forces, possibly by up to five, or eight times. The task force concluded that consideration should be given to selection of a site with high strength sub-soils when laying out substation switchyards.

- **Equipment Resonance**. If equipment or structures resonate during applied shocks, the material stresses will be increased. Initial evaluations by the task force showed that the failed SS equipment may have had rather low natural frequencies, close to the possible earthquake frequencies. Seismic frequencies in the range of from 10 Hz to 1 Hz seem to be the most severe. Substation equipment may be protected from this magnification effect by either detuning its natural resonance, or by damping its resonant motion, e.g. with mechanical dampers on footings.
- **Equipment Connections**. To minimise the high incidence of consequential failure observed in the Commission’s switchyards, it was necessary to review the connections between apparatus. The principle that motion from one item is not transferred, or does not resonate with that of an adjacent item, has been employed internationally (Okada, 1986) & (NZE, 1975). This can be done by increasing the slack (oversize length) of flexible conductors. Using these precedents, the task force

made an interim emergency recommendation that any flexible connector with slack less than 5% of total length should be remade to (ideally) 10% of length. But it also recommended further testing for the development of a new design standard.

6.6 Long-Term Review & Implementation.

As a result of these reviews and analyses into the Newcastle Earthquake, programs for modifications and monitoring of power system plant were urgently implemented to improve seismic performance. Further detailed studies were commissioned from the CSIRO to confirm appropriate structure modifications and develop standards for future plant (Chandrasekan & Walker 1990).

Shortly after the earthquake, however, the tremors of economic rationalisation shook NSW government authorities. The Electricity Commission was split into a number of separate, semi-corporatised organisations. A new authority, Transgrid, is now responsible for design, development, asset maintenance and operation of the NSW high voltage system. The company reports that it has completed the aggressive program of repair begun after the earthquake and has undertaken a system-wide seismic improvement program following the recommendations of the Committee of Review. Inadequate plant has been updated and spare plant installed as a temporary measure in the emergency phase has been replaced. New substation plant and replacement spares have been designed or acquired in accordance with the latest seismic standards of the power industry.

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