

EFFECT OF THE EDGE CUMBE EARTHQUAKE ON MECHANICAL AND PROCESS EQUIPMENT AT THE TASMAN MILL

by W. C. Hodge¹ and M. Macfarlane²

SUMMARY

This paper reviews the mechanical damage and the impact on the processes resulting from the March 2 1987 earthquake. Despite the potential hazards present in a pulp and paper mill as a result of the operating processes, there were no process related failures although there was significant damage to structures and some mechanical plant.

Mechanical damage can be seen to be relatively small being about one third of the total material damage and representing less than one per cent of the replacement value of the mill complex, highlighting the fact that such mechanical plants are not particularly high risks.

INTRODUCTION

On the afternoon of the 2nd March 1987 the Bay of Plenty region of New Zealand was rocked by a series of earthquakes which caused considerable damage in Edgecumbe, Te Teko, Kawerau, some of the small local rural communities and the surrounding farm country on the Rangitaiki Plains.

The approximate location of the major foreshock, mainshock and major aftershocks are shown in Figure 1 relative to Kawerau [1].

This paper deals with some mechanical and process aspects of the damage at the premises of the Tasman Pulp and Paper Company site adjacent to the township of Kawerau.

A spectral analysis of the major shock measured by the Geological Division of the DSIR at Matahina Dam (1) (approximately the same as at Kawerau) showed a good match with that at El Centro, California, in 1940 on which the New Zealand seismic design requirements are based. In other words the structures and plant were exposed to a "design" earthquake.

¹ Engineering Manager, Tasman Pulp and Paper Co. Ltd, Kawerau

² Senior Project Engineer, Tasman Pulp and Paper Co, Ltd, Kawerau

In Figure 1, attention is drawn to the 7.00 p.m. aftershock which was recorded as 5.2 on the Richter scale. However this was a very damaging shock which would have been around MM VIII in felt intensity, about the same as the main shock.

DESCRIPTION OF EXISTING MILL

Introduction

The Mill at Kawerau is situated between the Kaingaroa State Forest and the export port of Mt Maunganui; draws its supply of fresh water from the Tarawera River and is immediately adjacent to a major geothermal energy resource.

Since the Mill was first established in 1955 it has steadily expanded as indicated below:

<u>Year Established</u>	<u>Processes</u>
1955	No.1 Kraft Pulp Mill and No.1 Newsprint Machine
1956	Saw Mill
1962	No.2 Newsprint Machine
1974	No.2 Kraft Pulp Mill
1975	No.3 Newsprint Machine

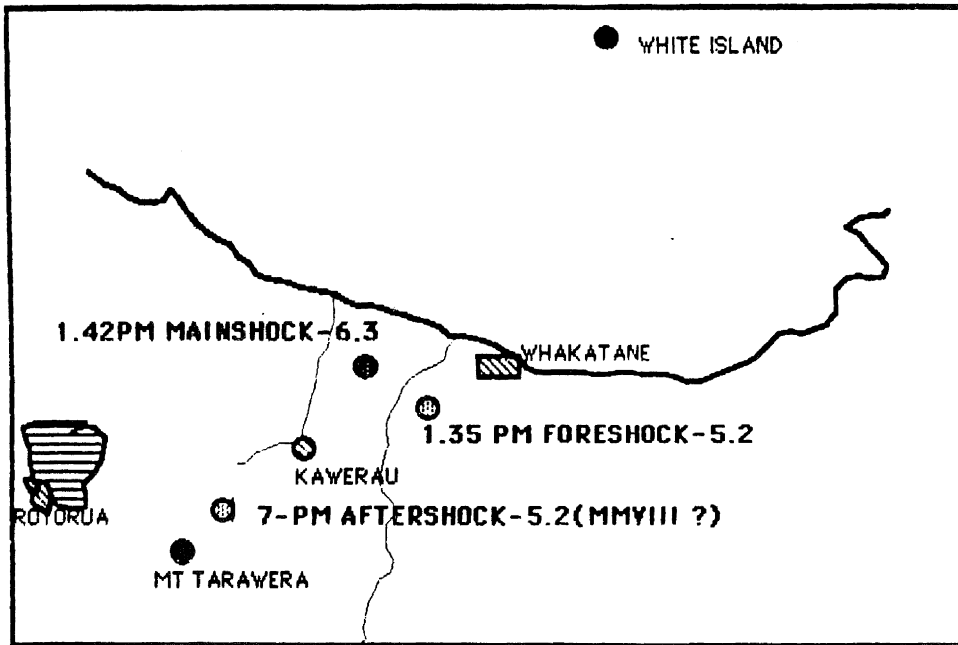


FIGURE 1. THE APPROXIMATE LOCATION OF THE MAJOR FORESHOCK, MAINSHOCK AND MAJOR AFTERSHOCKS RELATIVE TO THE LOCATION OF THE MILL AT KAWERAU

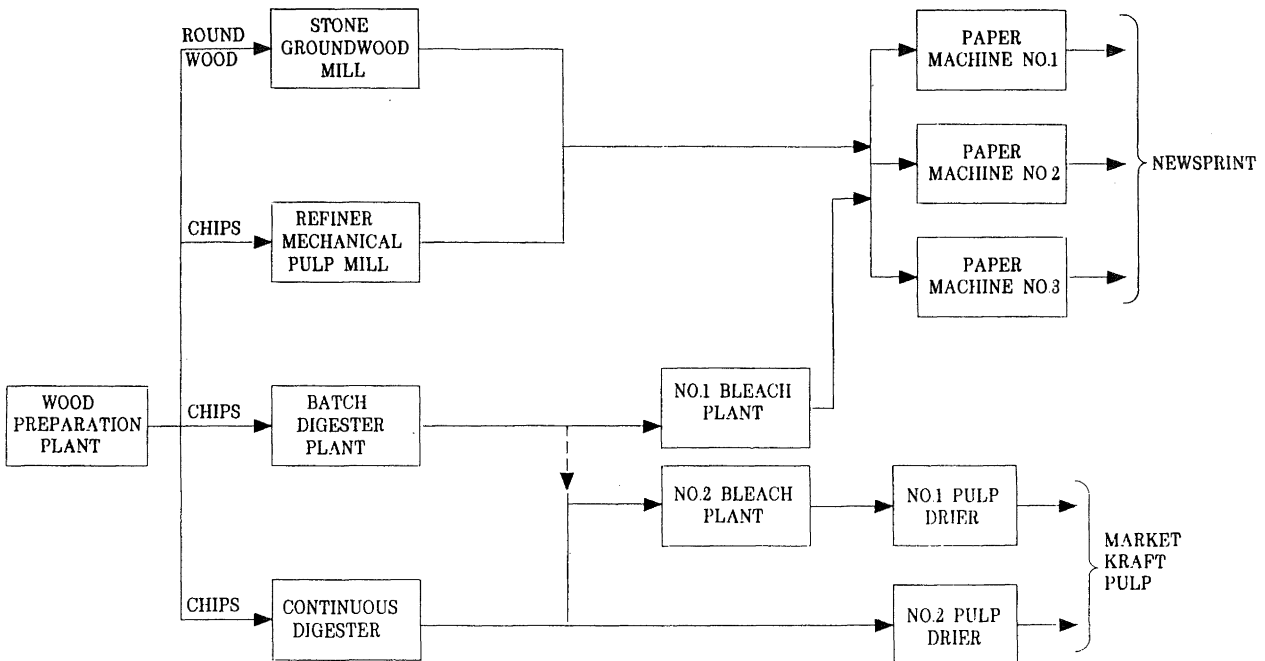


FIGURE 2A. SCHEMATIC OF THE MILL PROCESSES

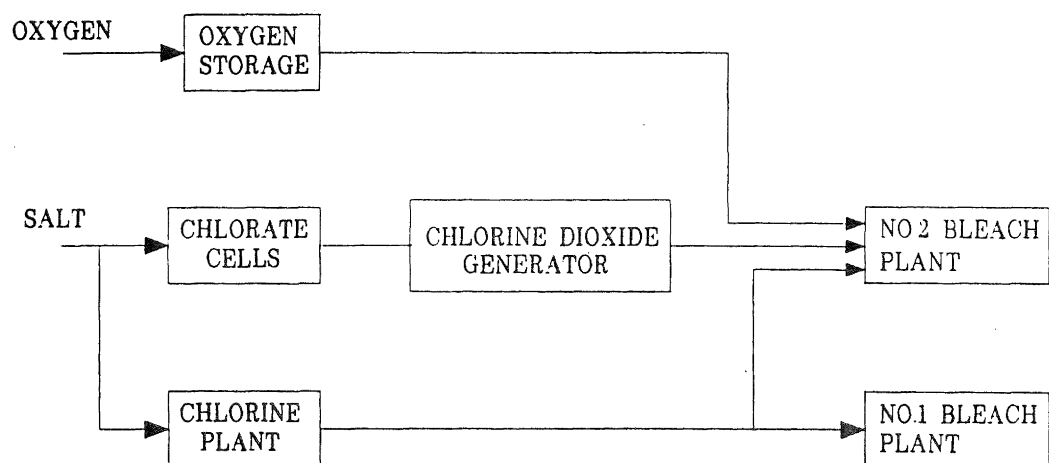


FIGURE 2B. BLEACH CHEMICAL PRODUCTION

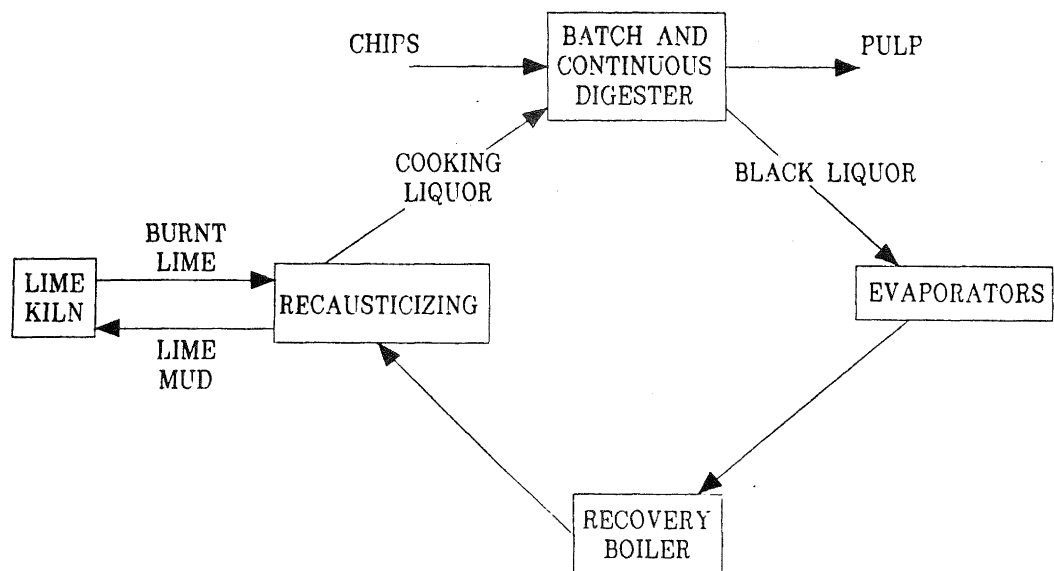


FIGURE 2C. RECOVERY FOR KRAFT PROCESS

The total annual rated capacity (saleable products) currently stands as follows:

<u>Product</u>	<u>Annual Saleable Production Capacity</u>
Newsprint	335,000 tonnes
Kraft Pulp	160,000 tonnes
Sulphate Turpentine	1,000 tonnes
Tall Oil	3,000 tonnes

A schematic outline of the various mill processes is given in Figure 2A while Figures 2B and 2C outline the bleach chemical production and the kraft process recovery respectively.

Wood Supply to the Mill

The main source of wood used in the Mill is the Kaingaroa State Forest.

Over 16 hectares of forest are cut each day to produce the wood required by the Mill of approximately 2,000,000 cubic metres per year.

Some of the wood required comes in chip form from sawmills.

Wood Preparation

All of the logs arriving at the Mill are debarked in the Wood Preparation Plant. They are then sorted into short logs for the Groundwood Mill or chipped for kraft and refiner groundwood pulping.

The bark and wood waste is hogged and conveyed to the Power Boilers for use as a fuel to produce process steam.

Kraft Pulp Mill

Pulping Capacity : 280,000 tonnes per annum

Pulp Drying Capacity: 170,000 tonnes per annum

Bleaching Capacity : No.1 Plant 80,000 tonnes per annum (for newsprint manufacture)

No.2 Plant 60,000 tonnes per annum

Main Equipment :

- Five Batch Digesters
- One Continuous Digester
- One Re-causticising plant
- Two Lime Kilns
 - . Chlorine-Caustic Soda Manufacturing Plant
 - . Chlorine Dioxide Manufacturing Plant
- Two Pulp Bleaching Plants
- Two Pulp Drying Machines
- Two Sets Black Liquor Evaporators
- Two Chemical Recovery Boilers

- One Black Liquor Oxidation/Tall Oil Recovery Plant

Wood chips produced from whole logs and sawmill residues are digested at elevated temperature and pressure in the presence of a solution of caustic soda and sodium sulphide (termed "white liquor") (see figure 2C). In this process the lignin which bonds the cellulose wood fibres together is removed. The residual liquor containing the lignin (termed "black liquor") is washed from the wood fibres (now termed "Kraft Pulp"). The black liquor after being concentrated in the evaporators is fired into the chemical recovery boilers. Steam is generated for process use and the sodium based chemicals are recovered as "green liquor". This green liquor is re-constituted into the active white liquor by the addition of burnt lime, produced from limestone in the lime kilns. This white liquor is re-used back in the digesters.

After the pulp has been washed it is dried on the pulp drying machines to produce unbleached kraft pulp for sale or it is bleached. No.1 Bleach Plant using chlorine and caustic soda produces semi-bleached pulp for use in Tasman's newsprint manufacture (see figure 2B). No.2 Bleach Plant, using chlorine, chlorine-dioxide and caustic soda produces bleached pulps which are dried on a pulp drying machine for sale. The bleaching chemicals are all manufactured on site.

Groundwood Mill

Stone Groundwood
Production Capacity : 550 tonnes/day

Refiner Groundwood
Production Capacity : 350 tonnes/day

Main Equipment:

Stone Mill

Thirteen Grinders
Three Rejects Refiners
Pulp Screening and Thickening Plant

Refiner Mill

Four Primary Refiners
Two Secondary Refiners
Two Rejects Refiners
- Pulp Screening, Cleaning and Thickening Plant

In the manufacture of groundwood or mechanical pulp, the wood fibres are mechanically separated from one another by attrition. In the Stone Mill, 1.2 metre long logs are held against a rotating carborundum grindstone. In the Refiner Mill woodchips are fed into a gap between stationary and rotating steel discs, the surfaces of which contain cutting bars. In both processes the pulp produced still contains the lignin of the wood and the wood fibres are a mixture of some whole fibres down to a very fine fraction of macerated fibres. It is these characteristics, which differentiate

groundwood pulp from kraft pulp which contains almost entirely whole fibres.

Paper Mill

Main Equipment:

Three Paper Machines

- All of same wire width 7.4 metres and maximum trim from the winders of 6.80 metres

No.1 Machine : Maximum design speed 625 m/min

No.2 Machine : Maximum design speed 900 m/min

No.3 Machine : Maximum design speed 1000 m/min

One Winder per machine

Two Rewinders

One Packing Line - Capable of handling up to 2300 rolls per day from the three machines

In the manufacture of newsprint a mixture of groundwood pulp and semi-bleached kraft pulp is used in the approximate proportion of 80%/20%.

The two pulps are prepared into a very dilute suspension of 1 part fibre to 99 parts water and is very carefully screened and centrifugally cleaned to remove any dirt particles or fibre bundles. After de-aeration this suspension is jetted on to the paper machine fine-mesh endless wire through the headbox slice. The sheet of paper is formed on the wire by removal of the greatest part of the water through the wire. The formed sheet is conveyed through the press section by felts, where further water is expressed from the sheet by the action of the presses.

The paper is then subjected to further water removal in the drying section of the machine where it is held in close contact with a series of steam-heated drying cylinders. Finally the sheet passes through the calender stack consisting of highly polished steel rolls which impart a smooth surface finish to the sheet. The rolls of newsprint from the paper machine are then transferred to the winder from which sets of tightly wound, customer size reels are produced. These reels proceed to the wrapping and weighing stations and then conveyed to the warehouse for despatch.

Power and Steam

Maximum steam generating capacity 525,000 kg/hr

Peak demand 375,000 kg/hr

Present internal electricity generation 23 MW

Electricity purchased from N.Z.E. 100 MW

Main Equipment:

- Two Chemical Recovery Boilers (burning black liquor)
- Four Power Boilers (burning hog fuel or oil)

- Two Turbo alternators (back pressure/pass out units)
- One Geothermal Turbo-alternator
- Four Geothermal Steam/Process Steam Heat Exchangers
- Process Water Treatment Plant
- Boiler Water Treatment Plant
- Effluent Treatment Plant

High pressure steam (4485 kpa) produced in the power and recovery boilers is reduced to process pressures of 1035 kpa and 345 kpa by passing the steam through the two back pressure pass out turbo-alternators. Approximately 20 MW of electric power is generated by these units.

HISTORICAL

As stated above, the original mill was built in the mid-fifties, expanded in the mid-sixties and again in the mid-seventies with progressive partial modernisations taking place continuously, generally driven by changing market conditions.

The mill construction and machine specifications reflected the state of the art at each stage and generally called for seismic design requirements using horizontal accelerations varying from 0.08g in the fifties (NZSS 95 Part IV) to 0.3g in the sixties and seventies (NZSS 1900 Chapter 8:1965 0.24g working stress design and NZS 4203:1976 0.3g) [Ref 2].

THE DAMAGE

General damage was widespread within the mill areas and no particular vintage of design fared significantly better than others except in some limited structural cases. Almost every building was damaged to some extent but mechanical plant fared reasonably well given the conditions of hot processes, aggressive chemicals and normal dynamic forces magnified by the impact of the earthquake. It can be concluded from the relatively low level of mechanical damage in the mill that the normal process design parameters give adequate safeguards for mechanical plant with only a few exceptions. Mechanical damage by value was of the order of thirty percent of the total material damage claim. About fifty percent of the total mechanical damage occurred on one newsprint machine.

Mechanical damage occurred in a variety of ways and in some cases was partly obscured from first inspections by debris from failures at higher levels.

In view of the nature of the millsite being geographically split into various areas, the following section deals with typical damage which is grouped as follows:

- (1) Woodroom
- (2) Pulpmill
- (3) Papermill
- (4) Steam Plant
- (5) Services

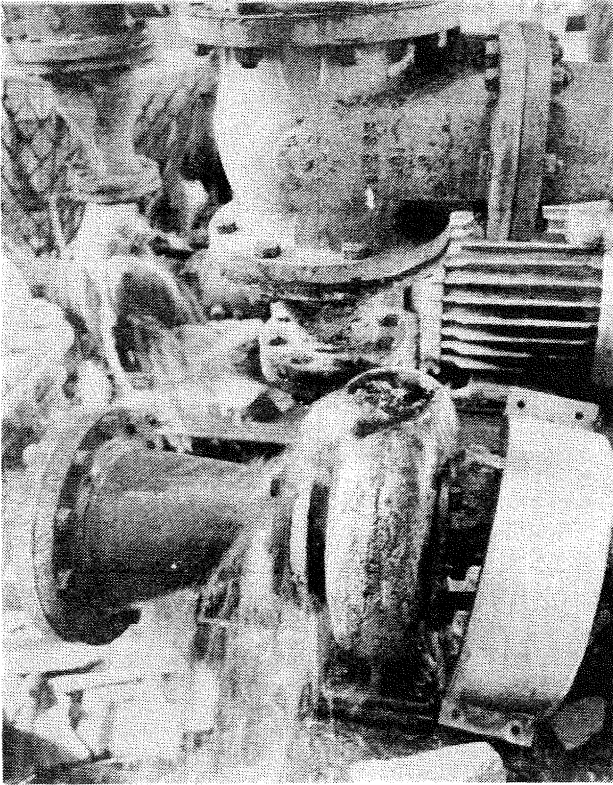


FIGURE 3. PUMPS WITH BROKEN CASTINGS

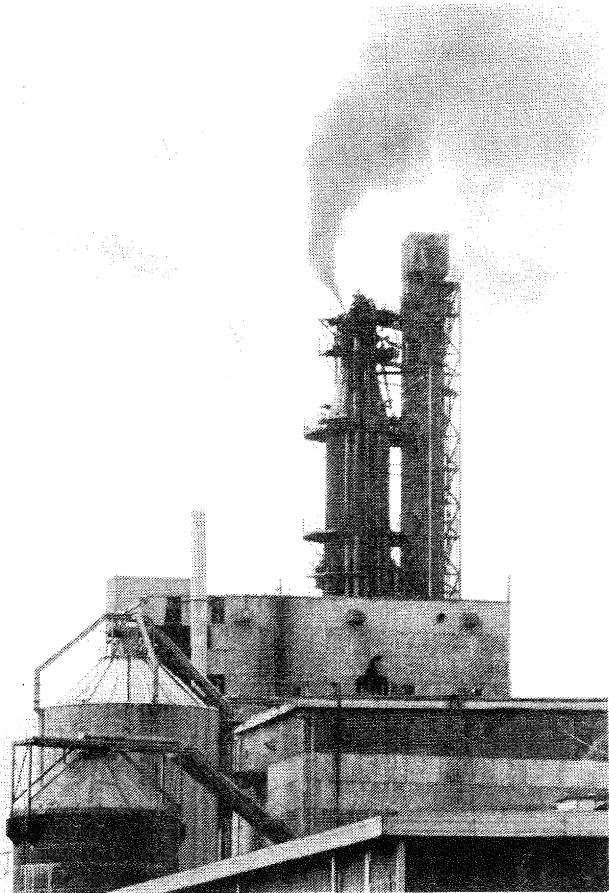


FIGURE 4. BROKEN PIPE ON DIGESTER

1. Woodroom

This area consists of various types of debarkers, chippers and conveyor systems designed for operation under high impact conditions consistent with log handling and wood processing systems. The very nature of the normal levels of design in this area proved to be adequate protection against the earthquake forces in terms of all mechanical plant and this area was among the first operations groups to be restarted following structural repairs and mechanical/electrical checkout.

2. Pulpmills

The No.1 Pulpmill (Batch Mill) mechanical damage was confined to misalignments on some drive units in isolated areas resulting from ground movement at the interfaces between different vintages of construction, notwithstanding the fact that each of two main areas of construction performed equally well in themselves.

The No.2 Pulpmill (Continuous Digester) area damage was most apparent in the structural field rather than in the mechanical field. The most spectacular failure being the permanent davit crane falling off the top of the Continuous Digester, a tall slender pressure vessel

some sixty metres high. The crane collapse was the result of failure of the holding down bolts. Beca, Carter [2] in a private study for Tasman showed that these bolts just reached the point of failure with the peak accelerations at the top of the digester which they estimated could have been as high as 3.0g. However the digester shell stresses did not exceed the design conditions. The major process impact here was the loss of black liquor from a broken pipe (see Figure 4).

Ground movement and local fissuring around the centre pedestal of No.2 Lime Kiln resulted in trunnion roller and guide roll damage, the loss of power and the rapid cooling of the kiln in the heavy rainfall which followed the earthquake resulted in serious deformation of the kiln body which had to be realigned by cutting the kiln in three places and replacing a section of the kiln body.

The Pulp Dryers suffered some damage to gears and the No.1 Drier pre dryer press support casting failed near the base requiring a new section of machine framing.

Chemical Plants

Tasman Pulp and Paper operates an Asahi membrane cell plant for manufacture of

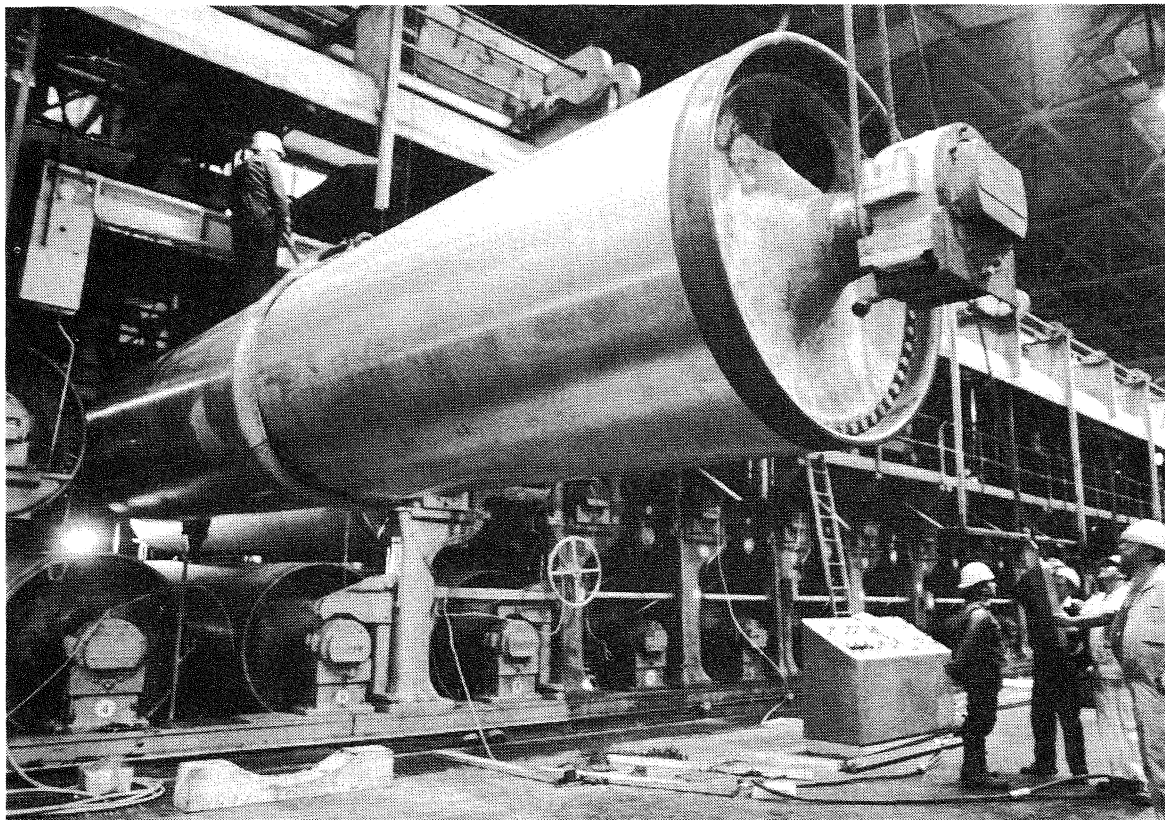


FIGURE 5. REPLACING DRYER CYLINDER ON NO. 2 MACHINE

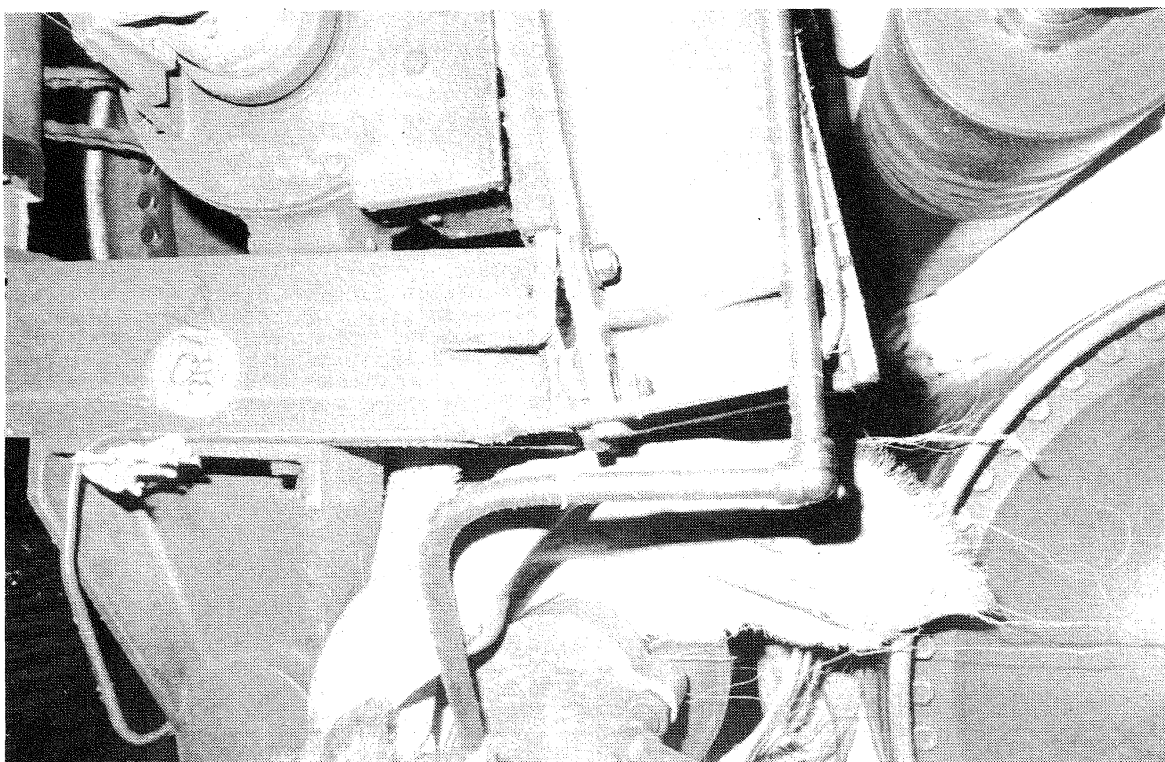


FIGURE 6. NO.3 MACHINE PART DRYER FRAMING

chlorine and caustic, and a single vessel reactor for manufacture of chlorine dioxide for bleaching. Liquid chlorine is stored on site in steel tanks and vapourised as required for the bleaching process. Chlorine dioxide is stored as water solution and pumped to the process as required.

In case of rupture of a chlorine line excess flow valves at the tanks shut off the flow. This system was not put to the test as no chlorine lines failed as a result of earthquake, an important non event under the circumstances.

A chlorine dioxide leak did occur from the violent shaking of a pipeline but the chlorine dioxide solution discharge was quickly isolated by the operators before any serious problem could arise.

The potential hazards of explosion, fire or major leak of toxic chemical did not occur at the Tasman Pulp and Paper mill as a result of the March 1987 earthquake.

Some sewers and underground water lines failed in a number of places requiring various types of repair, all of them difficult to locate, many only becoming apparent after start up, and inspections were still being carried out at Christmas 1987.

3. Paper Machines

The three newsprint machines were in various operating modes at the time of the major shock, No.1 Machine was running at 600 metres per minute, No.2 Machine was at about 400 metres per minute in the course of stopping following the major foreshock, while No.3 machine was running at 950 metres per minute.

The nature of damage was similar on all three machines but the magnitude was greatest on No.3 Machine. It is also likely that some damage occurred in all areas during the major aftershocks on the same day.

An index of machine damage would be as follows:

Machine	Index	Design Speed M/Min	Speed	Start-up
			@ Main Shock M/Min	
No.1	1 (Low)	615	600	9th April
No.2	2	900	400	15th April
No.3	8	1000	950	23rd July

Figure 7 shows a circle diagram of No.1 Machine, the oldest and lowest producer of the three machines. No.3 Machine Dryer Section took the heaviest damage and not surprisingly was also out of commission for the longest period. It took fifty seven days to dismantle the machine and fifty nine days to rebuild it. The width of all machines is nominally seven metres with lengths around 100 metres, the height of each machine varies slightly but in the order of 14 metres from the basement to the top of the press sections.

In the vendor analysis of No.3 Machine the guide roll components should have survived the basic accelerations, however the idealistic design conditions did not prevail and the combination of possible acceleration magnification and the operation of the guide roll dynamic systems at the instant of shaking, the effect of the unusual multi-directional loads (roll weight, fabric tension, couple from control system, couple from instantaneous differential vertical earthquake movements, etc.) would and obviously did take the compound stresses right up to the limit of the cast iron material. Most makes of machines supplied today would withstand a similar event with a lesser degree of damage.

Virtually every machine column on the front side drivers failed at the sole plate level, most gearcases on the backside continuous gear train failed and all guide and stretch roll housings were damaged to some degree.

Several areas suffered failures of fire sprinkler systems as shown in Figure 9, a particularly sorry state of affairs given the compulsory nature of these systems for insurance, the limited purchasing opportunities for such systems and the very high probability that the time of greatest need could be after an earthquake. Poor fixing details, lack of piping flexibility, and high risk joint details were important factors in these failures.

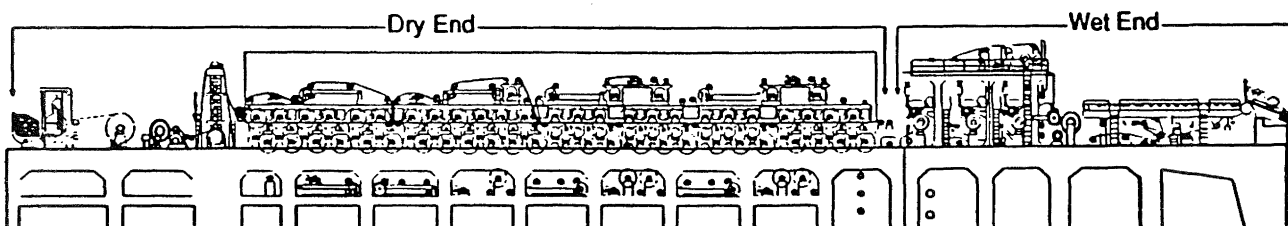


FIGURE 7. NO.1 NEWSPRINT MACHINE

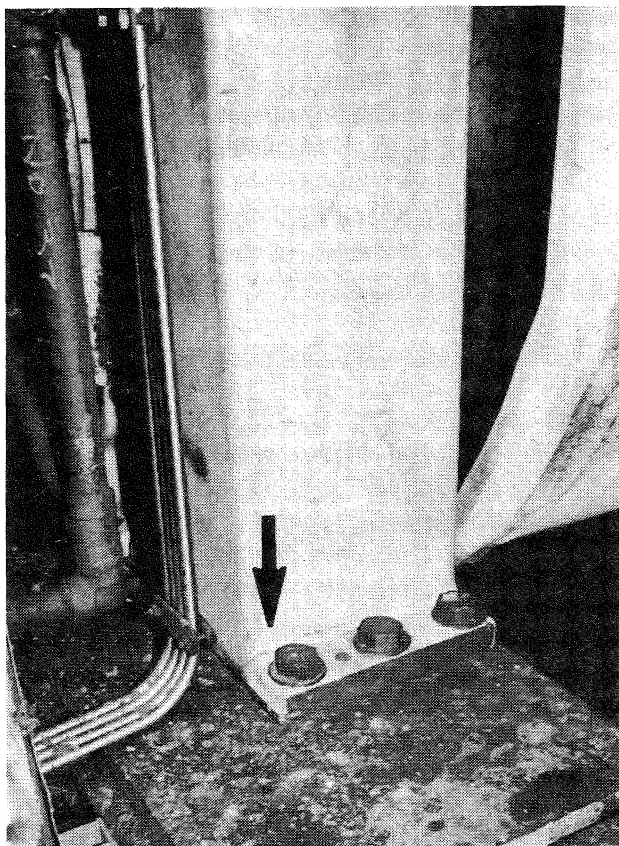


FIGURE 8. COLUMN BASE FAILURES NO.3 M/C DRYERS (FRONTSIDE).

Also visible in the same figure are some light fittings on the floor, they were particularly dangerous, having a weight of around fifty kilograms, many fell as a result of suspension chains failing during the violent shaking.

Damage in the Press and Wire sections consisted of casting failures and misaligned framing while the headbox apron board on each machine was badly distorted.

The process stock, white water and steam systems suffered varying degrees of damage. The extent was not as wide as may have reasonably been expected given all the conditions.

Calender stack soleplates, reel drum support legs and the reel arm gearbox all suffered some degree of damage.

Damage to the bridge type house cranes was confined to failure of rail studs in areas where the cranes were parked.

Plant damage in the mechanical pulp mill areas was quite small, there being some displacement of the disc filter and misalignment between the motors and refiners in the Refiner Plant, in addition some stator wedges were dislodged in the refiner motors (each five megawatts). There was no significant mechanical damage in the Stone Groundwood Mill. Some light weight ventilation ducting fell from the roof supports.

It goes without saying that any damage to a paper machine is in itself a process interruption but there were no explosion or bursting type of failures in this process system.

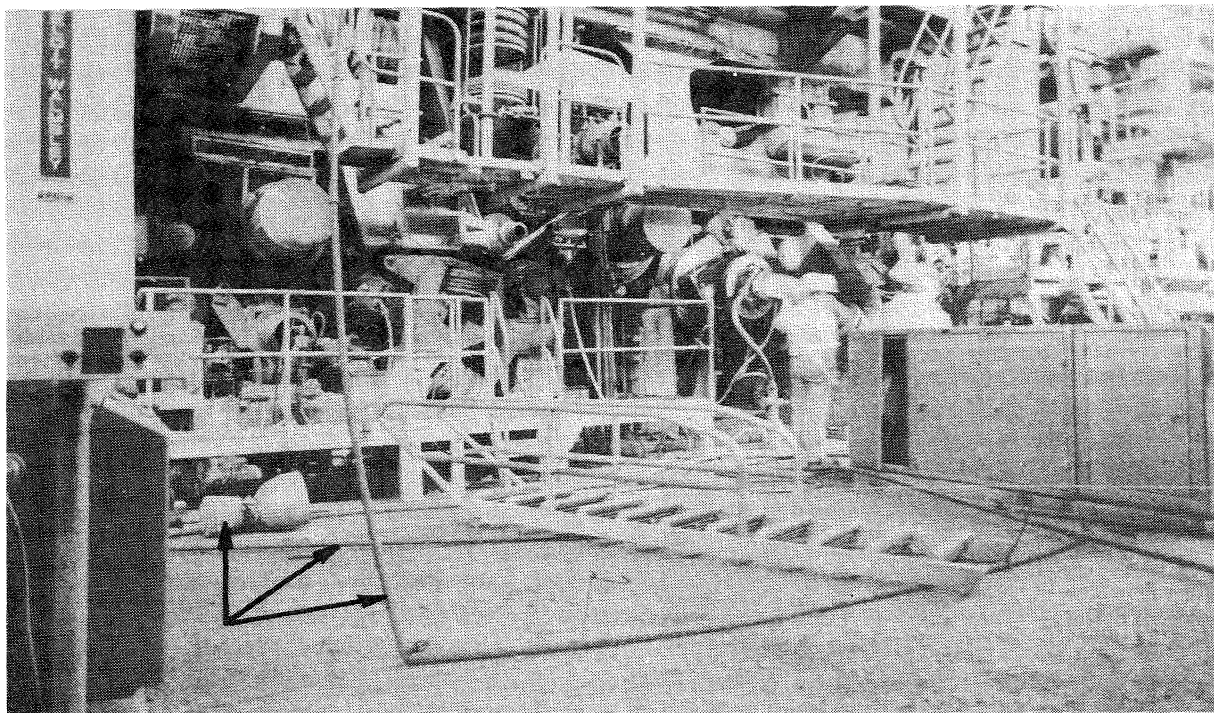


FIGURE 9. FALLEN SPRINKLER PIPES AND LIGHT FITTINGS

4. Steam Plant

This area was not free of mechanical damage but the scope of such damage was relatively small and other than the specific items mentioned below was limited to the displacement of steam lines from supports and a small incidence of spring collapse in some hangers.

Although all the turbines were running at the time there was no apparent earthquake related damage to the turbines. However this observation must be tempered by the fact that we were still uncovering earthquake damage in many areas, nearly a year from the event.

Recovery Boiler

Overseas experience has been such that Recovery Boilers have caused most major shut downs of pulp mills. Industrial Risk Insurers (IRI) [ref 3], report that 70% of business interruption involving the insurance claims in American Pulp and Paper industry was caused by Recovery Boiler failures. Over past years there has been one major Recovery Boiler failure every year for every 100 boilers in operation. Each recovery boiler explosion has the potential to cause several million dollars of damage and hence those units receive particular attention from the insurance industry.

Most recovery boiler explosions are caused by smelt water reactions. Smelt is formed by burning the residues from the cooking process which contain dissolved organics from the wood and the caustic chemicals used in pulping.

Burning of the organics provides steam for the process while cooking chemicals are recovered by dissolving the smelt in water in a controlled fashion.

Smelt-water reactions have occurred overseas where a boiler tube has ruptured during operation allowing water to discharge onto the molten smelt. The shock waves generated by a smelt water explosion can be sufficient to severely distort the tube banks of the furnace.

In a recovery boiler vertical expansion of the tube banks is allowed by "earthquake stops" which provide for vertical movement but restrain any horizontal movement of the tube bank relative to the structural supports. During the March 1987 earthquake the "earthquake stops" were damaged with some limited failure. These "earthquake stops" achieved the design aim and prevented impact of tubes on the structure from taking place thereby avoiding the risk of explosion in this case.

Many of the earthquake stops on No.2 Recovery Boiler collapsed but fulfilled their intended role, the only significant damage, apart from some structural parts, in this unit occurred in the economiser/backside generating bank where a few tubes and economiser baffles failed. Some outlet ducting on this unit required replacement expansion joints. Outlet

ducting from the precipitator was damaged by the collapse of the stack on No.1 Recovery Boiler.

Much of the refractory and the precipitators on No.1 Recovery Boiler were badly damaged but are seen primarily as structural failures.

It is of interest to note that registered pressure vessels did not appear to suffer any damage in any area of the mill although in a few cases stretching of the holding down bolts was apparent.

5. Services and Effluent Disposal

The raw water intake and pumping station built at the time of the original mill construction was badly damaged by ground movement resulting in tilting of the ground level concrete slab supporting the pump/motor rafts together with causing damage to underground pipes.

Damage from subsidence and ground movement opened up joints on the main effluent line and many of the underground process sewers. There was some slight tilting of the clarifier and remedial action is yet to be decided.

CONCLUSIONS AND RECOMMENDATIONS

The nature and extent of mechanical plant damage and the impact on processes was such as to give confidence that most process and equipment design parameters in use are sufficient to safeguard the plant against excessive damage in a reasonably major seismic event. As with all design situations here are areas that can benefit from some improvement. Such opportunities tend to be limited to specialty applications although the incidence of near miss situations suggest that larger margins could be incorporated at a relatively modest cost in some areas. It was pleasing to note that most of the "standard" designs prevented other than minor mechanical and process damage.

Some superficial guidelines as follows may be useful without being all embracing.

1. Combine pump and tank foundations to minimise suction line damage particularly if the tank contains dangerous liquids.
2. Combine pump motor baseplates to avoid differential misalignment between pump and motor.
3. With adjacent structures of differing stiffnesses ensure adequate flexibility in process piping and conveying systems to take up the differing response of such structures.
4. In checking the effect of seismic accelerations on plant, examine the total integrated support system and elevations to allow for or avoid magnification of these accelerations. Employ analysis techniques having dynamic capability but with careful choice of assumptions.

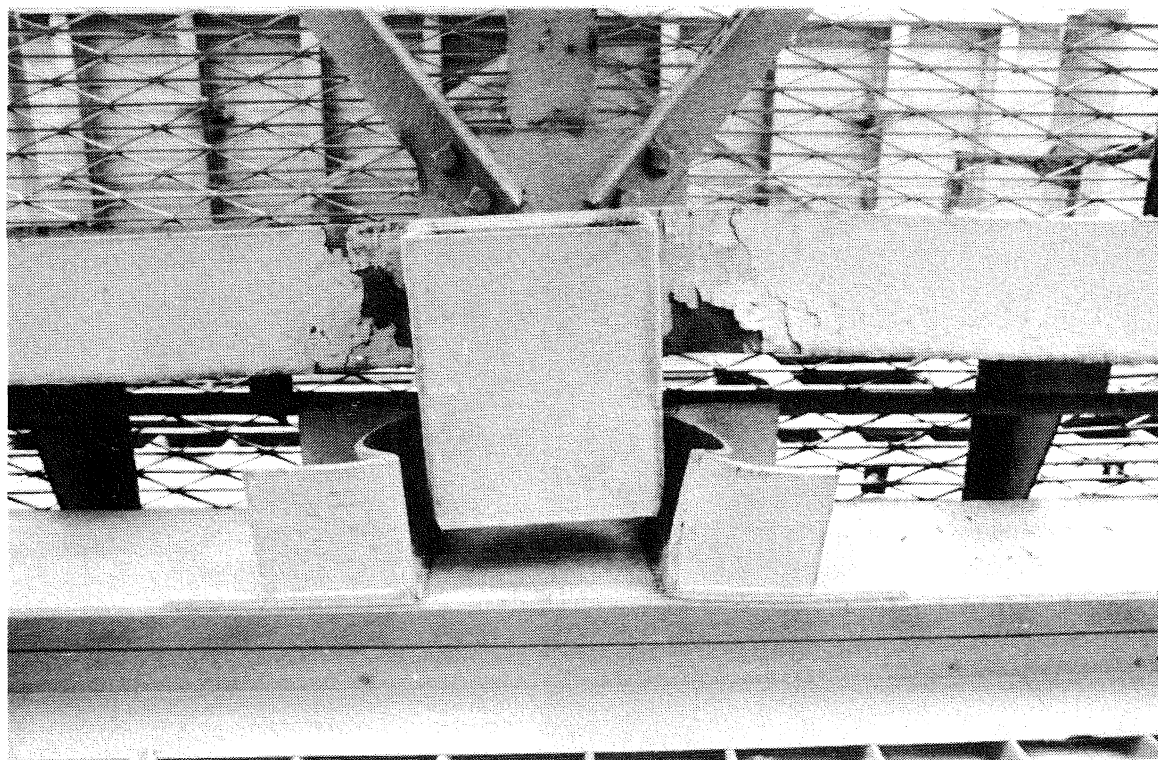
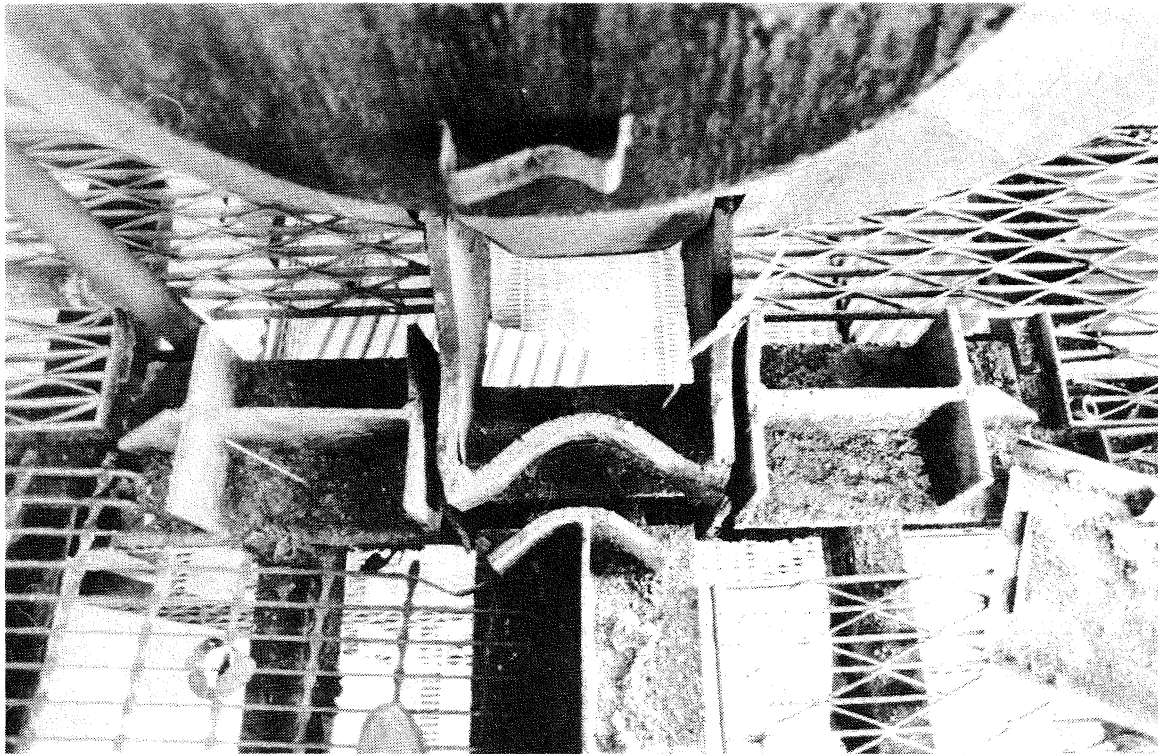


FIGURE 10. COLLAPSED EARTHQUAKE STOP - NO.2 RECOVERY UNIT

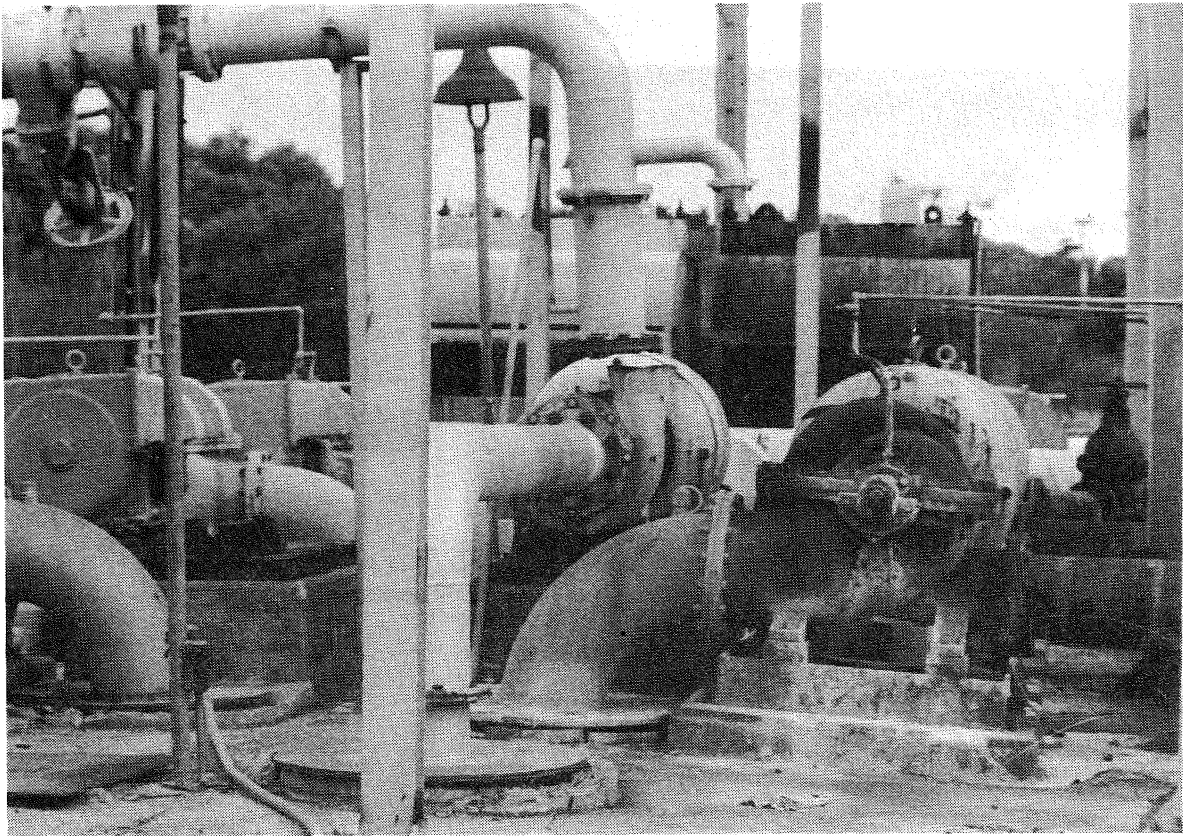


FIGURE 11. RAW WATER PUMPS SLAB TILTING

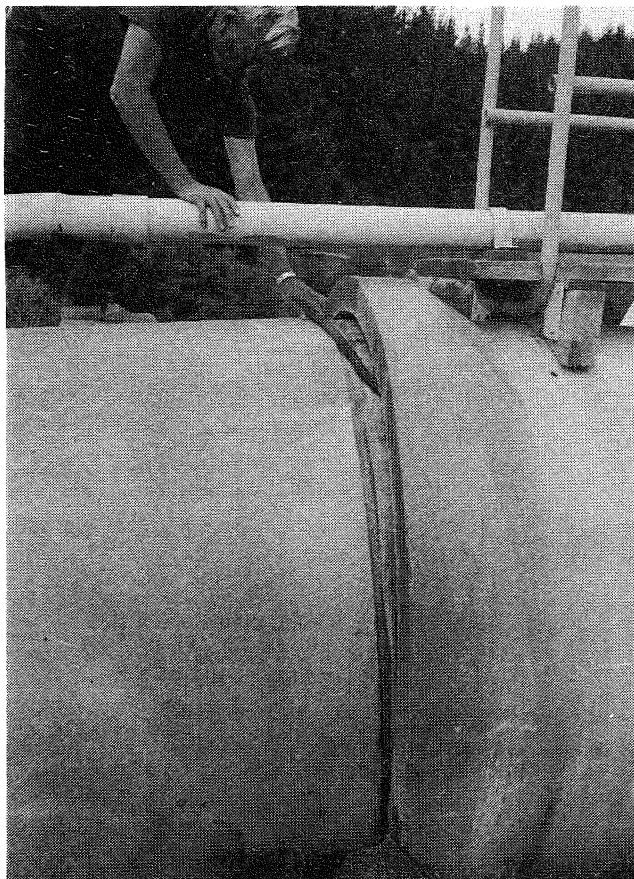


FIGURE 12. EFFLUENT LINE DAMAGE

5. Have vendors submit calculations of machine or component design with appropriate allowances so that the requirements of (4) can be checked, the vendor may not have all of the relevant information for a total assessment.
6. When incorporating fibre glass or special materials ensure that the load carrying capacity of connections and supports are adequate for seismic conditions.
7. At the layout stage it could be useful to review hazards from surrounding or adjacent potential failures, including access and egress, and consider the outcome of such things as falling towers, pipes, chimneys, concrete etc.
8. Although the Tasman plant didn't suffer any direct failures from differential aging of plant it would be prudent in existing plants to inspect for possible hidden defects from corrosion, changes to supports or structures or incomplete construction details which could change the response to shaking. Bear in mind that the elements of plant and structures don't necessarily deteriorate at the same rate so that units that seem uniformly capable of absorbing violent shaking may in fact include some weakened elements.

Physical restoration of the whole plant was achieved in good time and at a modest cost. In all engineering applications it is obvious that having a plan generates a better result than having no plan. It is therefore worth considering the need to have a "disaster plan". The earthquake resulted in the mill having no power, water, communications and fire fighting capability for varying periods of time. The intensity and frequency of after shocks made inspections somewhat hazardous for several days after the event and even into April and May shocks of 4 to 4.5 on the Richter scale were still being experienced.

Even in a situation of no apparent damage, shutdown time will be lengthy because of the need to check alignments, bearing conditions, control systems, power supply systems, turbine internals, boiler and pressure vessel and housecrane conditions and arrange re-certification, piping crack and displacement checks, and re-establish all services.

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