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DAMAGE DURING NOVEMBER 27, 1971 ROCKBURSTS IN NUNDYDROOG MINE IN KOLAR GOLD FIELDS

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INTRODUCTION

Kolar Gold Fields are situated in Kolar District, Mysore State. The geology and petrology of the Kolar Gold Fields has been described by Pryor (1923-24 in Krishnamurty 1971) and Burdon (1947, 1957 in Krishnamurti 1971). Gold occurs in quartz veins in hornblende schist country rock. The major auriferous veins, the Main Reef Champion lode and West Reef Oriental lode are being worked by Bharat Gold Mines (Private) Limited (BGML). These veins dip at steep angles of about 80° and show variations in width as well as gold content. The folliation of the country rock in general is parallel to the veins.

'Rockburst is a term applied to sudden and voilent failure of rock on a scale sufficient to endanger excavation surfaces, structures, equipment or personnel'. Rockbursts are of frequent occurrence in Kolar Gold Field Mines. As mining became deeper, these have become increasingly numerous and pose serious problems in ground control and safety. These problems have been investigated by various workers (Crowle 1931 and Apalding 1938, in Peele and Church 1941) in the past and a special Rockburst Research Unit has been established since 1955 which has taken up systematic study of the problem and has carried out instrumentation for determination of strength characteristics and stresses in the rocks and ground movements around stopes and other openings (Bhattacharya 1961, 1962, Miller 1965, Krishnamurthy 1966, in Krishnamurthy 1971 ; Taylor 1960-61, and Krishnamurthy, Miller and Potts 1965, in Krishnamurthy, 1969).

This paper describes the damage in the region due to November 27, 1971 rockbursts and gives recommendations for repairs of existing damaged structures and design of new structures to resist future rockbursts in the region. Suitable instrumentation and collection of strong ground motion data during future rockbursts for dynamic design of structures has also been suggested.

ROCKBURST

The rockburst of 27th November 1971 Nundydroog Mine, working the West Reef, was one of the large rockbursts in the region which was responsible for considerable damage in the under ground mine, and many houses on the surface were badly shaken producing major fractures in the walls and along openings. The seismic waves produced by the sudden rock fracture were reported to have been felt upto distances of 70 to 100 km from the mine and were recorded at the seismological observatories at Kolar Gold Fields, Hyderabad, Kodaikanal, Colaba, Poona, Madras and other observatories and at Gauribidanur Seismic Array. The main rockburst tremor had Richter's magnitude 4.6 (surface waves) evaluated from the seismogram record at the Seismological Observatory of the National Geophysical Research Institute at Hyderabad. Field investigations suggest that the peak ground accelerations exceeded 0.5 g. but as the time

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base of the acceleration pulse must have been small and the duration of the strong ground motion was not large most of the structures escaped severe damage.

DAMAGE INSIDE MINE

Considerable damage occurred underground between 3400 and 6200 levels (ft below ground level), with fall of loose rocks, debris and granite walls, shaling of back and front walls, lifting of the haulage tracks, buckling of the steel sets and collapse and closure at different points. Figures 1 and 2 shows the general location of the underground damages. Greater damage was noted in between the dykes which traverse the reef. There was more crushing of the country rock at the contact of the porphyritic dolerite dyke in the north and the dolerite dyke about 240 m (800 ft) towards south, and the dyke rock itself was fractured and developed cracks from 3600 to 4500 levels. The width of the damage along the levels was about 300 m (1000 ft) and in the cross cuts the damage was mostly confined to the region within the porphyritic dolerite dyke and dolerite dyke towards its south The damage from 3600 to 4500 level thus appears to be directly related with the zone of rupture during the rockburst, and the damage at other levels was a result of the dynamic forces due to the stress wave propagating from this rupture zone.

The failure surface along which the rock mass was ruptured during the rockburst thus appears to have a length of about 270 m (900 ft). Slickensides striations were noted to have developed on fracture surfaces at 4000 level near the southern contact of the porphyritic dyke, which indicate a relative movement of the hanging wall towards north with respect to the foot wall. No reliable estimates of the net slip of the rock fracture could be observed. However displacements varying from few mm to 1.5 cm were noted along the fractures. The magnitude of the tremor resulting from this rupture could be approximately evaluated from the following relation (Bonilla, 1970):

$$M_b = 1.4 \quad \frac{\log LD^2}{1.9}$$

where M_b is the Richter's magnitude (body waves), and L and D are the length of the rupture surface and the displacement along the rupture surface in cm respectively. With L=270 m and D=1.5 cm the magnitude of the rockburst tremor comes to about $M_b = 3.9$ (body waves). This compares well with the reported magnitude $M_s = 4.6$ (surface waves) for the main event.

DAMAGE TO BUILDINGS

Damage to buildings had occurred during earlier rockbursts in the mines. Most of this damage was reported to consist of fall of plaster, cracks in masonry walls and arches, and collapse of portions of stone masonry walls. During the November 27, 1971 rockbursts, the damage to buildings was of similar nature, but it extended over a large area of the Estate of the BGML, and Factory Area and Township of Bharat Earth Movers Limited (BEML).

BUILDINGS IN BGML ESTATE

Most of the buildings in BGML Estate are one to two storeyed sturctures built in random rubble or dressed stone or brick masonry, with sloping roofs of galvanised corrugated iron sheets (often covered with Mangalore or pan tiles) or asbestos cement sheet or Mangalore tiles or pan tiles. The common pattern of damage in the buildings and other structrues in the region was found to be as below:

(a) **Bungalows**—Most of the bungalows are in the northern parts of the BGML estate. These are mostly old structures with thick dressed stone masonry walls with arches over large openings and high ceilings. Verandahs consisting of brick pillars or timber posts surround the rooms, and at places the same have been enclosed by brick filler walls to

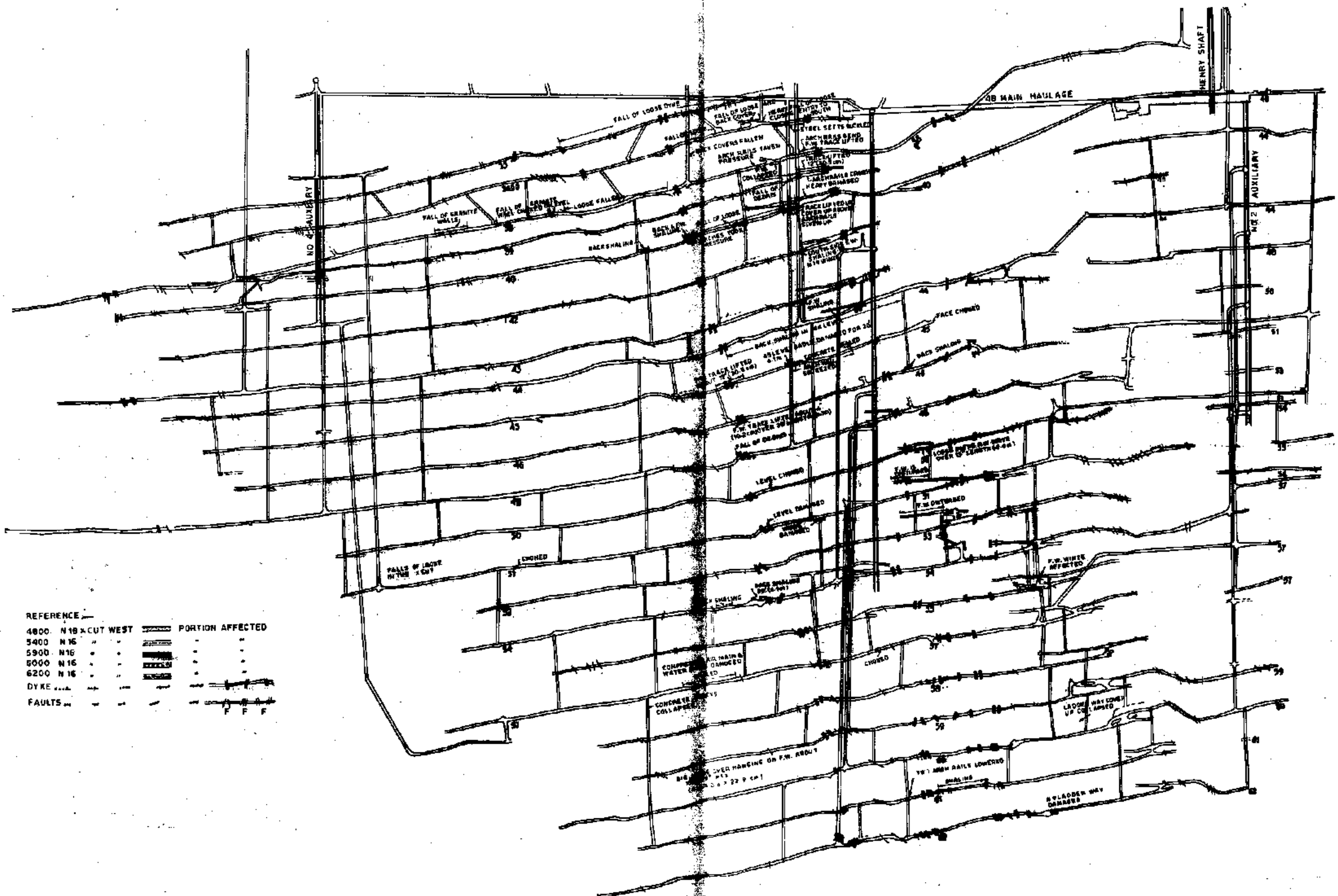

Fig. 1. Staggered plan of Nundydroog mine (100 ft. apart 3500 to 6200 Level) showing the locations affected due to rock burst on 27.11.71 at 2.16 hours.

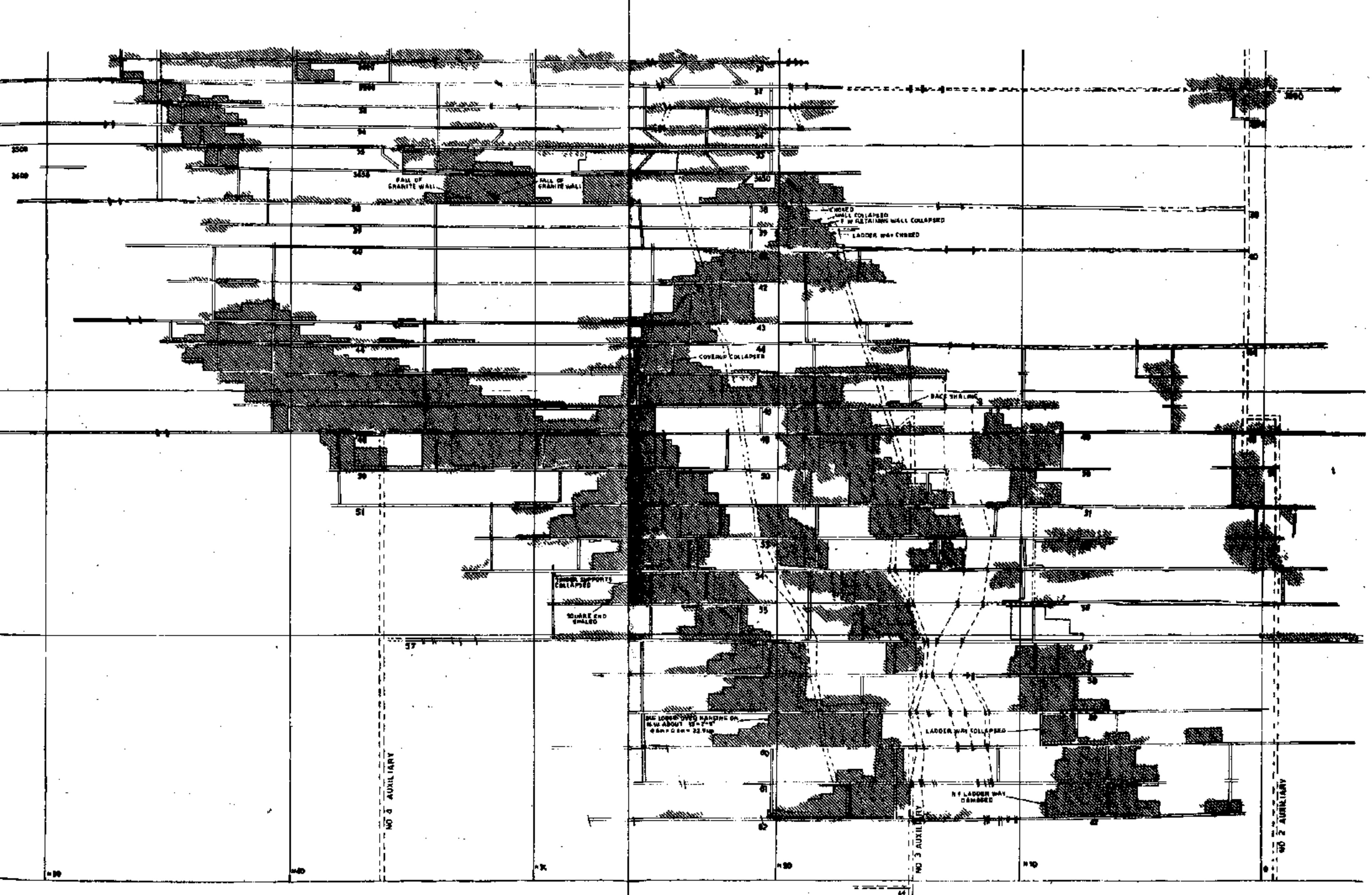

Fig. 2. Vertical section showing locations affected in the stopes of Nundydroog mine due to rockburst on 27.11.71 at 2.10 hours.

provide additional space. Partition walls of "Dhajji Divari" Kashmir type construction (timber frame with brick in-fills) exist on the second storey levels of several houses. Most of the bangalows have sloping roofs of galvanised corrugated iron sheets covered with Mangalore tiles or pan tiles. In some bungalows later additions in brick masonry have been made. The old construction is in lime and cinder mortar and recent additions and repairs are in cement mortar.

Almost all the bungalows suffered damage. Dressed stone masonry developed cracks from window and door opening (Fig. 3) whereas random rubble masonry suffered greater damage, often with bulging and partial fall of masonry (Fig. 4). The damage in brick masonry in cement mortar in general was less as compared to stone masonry construction. The most common type of damage was the development of vertical and inclined cracks from the top of the gable to the corner of openings, horizontal cracks at lintel levels between openings and branching towards roofs and sides, inclined and vertical cracks from window sill levels towards foundations (Fig. 5), vertical and branching cracks at junctions of main walls and cross walls (Fig. 6) and cross fractures and radial cracks in solid masonry walls (Fig. 5). Development of cracks and fall of plaster in the walls at roof level and above the ventilators (Fig. 3 and 4), and shattering of plaster and exposing the masonry indicating relative movement between the heavy tile covered roof and walls was also very common. Brick filler walls and "Dhajji Divari" partition walls developed cracks along its margins and shifting of bricks occurred at few places. Such filler walls and partition walls were not tied with the columns or walls or timber framework to resist their movement. Diagonal timber strips (Fig. 7) covering the brick filling in "Dhajji Divari" construction prevented their collapse. Timber units behaved better and resisted the rockburst with only movement of filler material along the margins.

Brick pillars supporting the roof in verandahs developed horizontal cracks at different heights (Fig. 5) from the base with slight lateral shift towards or away from the rockburst centre. Timber posts supporting such roofs showed similar shifts at the base. Parapet walls in verandahs developed cracks and showed similar lateral shifts.

Almost all unsupported arches developed cracks (Fig. 8) along key stones as well as neighbouring stones. These had suffered damage in earlier rockbursts and many of the arches had been strengthened with steel arches to conform to their intrados. The sides of the arch were either taken to the foundation or tied together with steel rods at the top. Such supports prevented further damage to the arches in the present rockburst.

(b) Housing Colonies—Various types of row houses (lines) and individual quarters have been constructed in the BGML Estate. These consist of (i) stone masonry construction with galvanised corrugated iron sheets (often covered with tiles) or tile roofs, (ii) brick masonry construction with asbestos cement sheet or galvanised corrugated iron sheet (often covered with tiles) or tile roofs, (iii) pre-cast column panel reinforced cement concrete structures with roof of various types as in (ii), and (iv) split bamboo mat ("tatty") houses with tile roofs. The tatty houses had a basic timber framework supporting the tile roof and the split bamboo mats generally plastered with clay, act as walls. These (Fig. 9) did not suffer any damage except that roof tiles in some houses got displaced. The pre-cast R. C. C. houses (Fig. 10 and 12) also did not suffer any damage, except in houses with tile roofs, in which displacement and rattling of roof tiles occurred. However in two houses in Kennedy's line concrete posts were reported to have come out and the slab joints had opened. This probably resulted due to poor embedment of the posts.

Old stone masonry houses in mud and cinder mortar suffered the maximum damage (Fig. 11 and 12). The walls at the gable ends developed major cracks, with fall of plaster and necessitating their demolition (Fig. 11) and rebuilding, and partial collapse of walls in some cases (Fig. 13). Cracks in the walls and along junctions with cross walls and partition walls, corners of windows (Fig. 13) and door (Fig. 14) and along arches (Fig. 15) were developed extensively. Old construction in brick masonry suffered similar damage,

Fig. 3. Cracks in western wall near roof level, extending from window and ventilator openings at Shri A. C. Hiriyanniah's residence.

Fig. 5. Development of cross fracture and radial cracks in the wall and rupture of the masonry pillar on the east gable end side of Shri M. C. Ramasamy's residence. Cracks from window sill level extend down towards foundation.

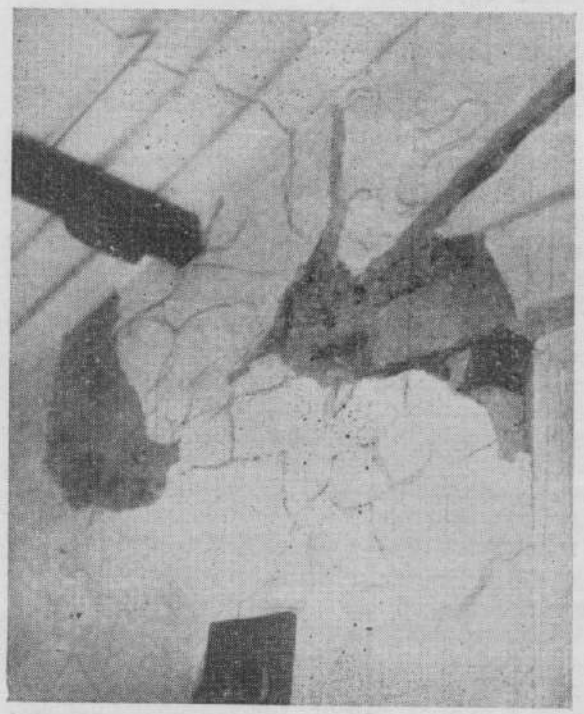

Fig. 4. Bulging and damage of random rubble masonry wall at Shri V. R. Vinayagan's residence.

Fig. 6. Development of cracks in stone masonry walls at junction of walls, at roof level and along the door openings at Shri H. C. Ramasamy's residence.

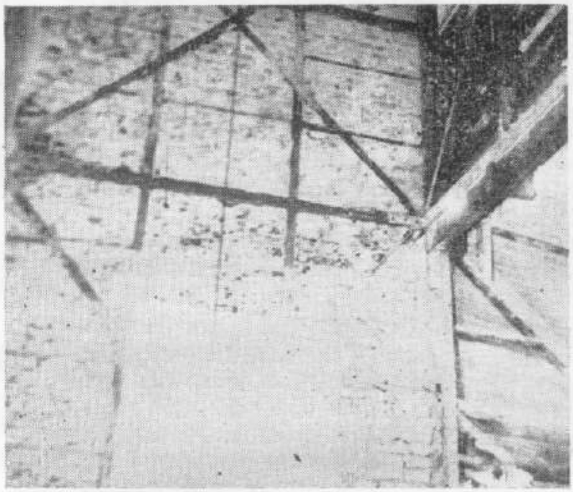

Fig. 7. Brick panels in timber frame (Kashmir type-Dhajji-Diwari construction) forming partition walls in second storey level at Shri M. H. R. Rao's residence, which developed extensive cracks with displacement of bricks, necessitating their dismantling.

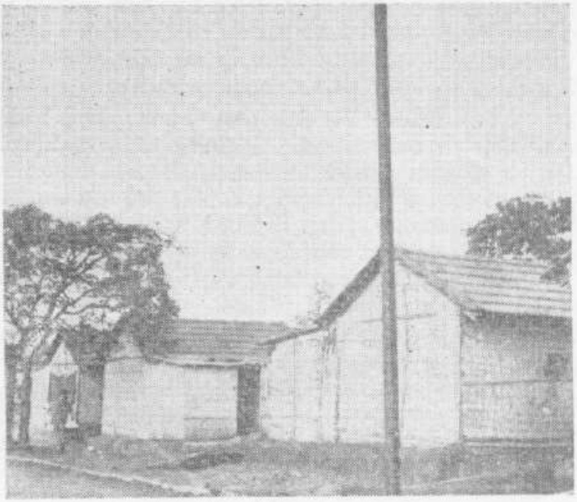

Fig. 9. Tatty houses, with walls of split bamboo mats nailed on timber posts, supporting the tiled roofs, which did not suffer any damage.

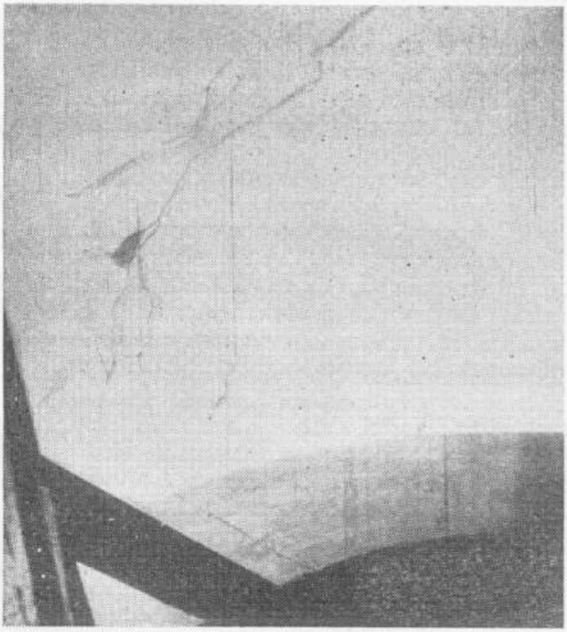

Fig. 8. Development of cracks in masonry arch in Shri A. C. Hiriyanniah's residence.

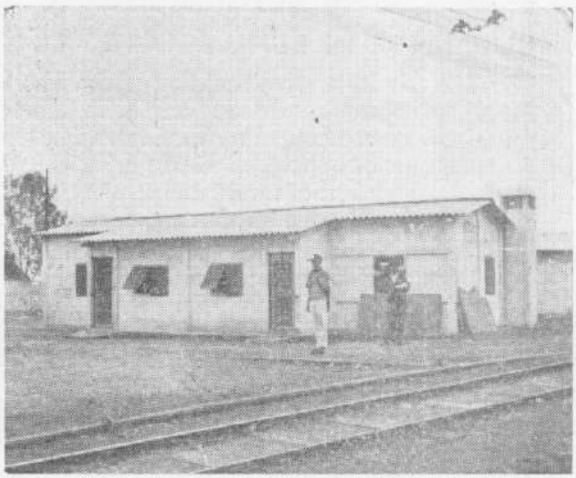

Fig. 10. A prefabricated post panel reinforced concrete house which did not suffer any damage due to rock burst.

whereas comparatively lesser damage was noted in newer construction of this type. The difference in behaviour of old and new houses is due to the fact that the old houses already developed cracks in earlier rockbursts consuming considerable part of their energy absorption capacity already so that wider and more extensive cracks occurred in the present rockburst than the new houses which could absorb the energy by finer cracks only.

(c) Other Structures—The Office buildings of the BGML suffered damage similar to that in bungalows. School buildings, Dispensary, Polytechnic Institute, Sports Club and Drama Halls, and temples and churches in the region, which were in masonry construction with sloping roofs, showed similar behaviour. Few recent construction in stone masonry (Fig. 16) and brick masonry (Fig. 17) with R. C. C. flat roof developed cracks in wall at roof level as well as along corners of door and window openings. Prefabricated reinforced concrete (Fig. 10, 12 and 18) and steel structures did not suffer any damage.

Large sheds housing the various plants around Henry Shaft showed minor damage and cracks in the upper parts of high masonry walls near the roof level and along gable ends. In some cases old cracks resulting from earlier rockbursts and other causes had reopened. The concrete base of the back brace of the head frame of the Henry's shaft developed cracks (Fig. 19). The masonry bases of the evaporation cylinders resting on timber sleepers in the Air Conditioning Plant developed cracks near the junction of the sleepers. Vertical cracks extending from the top in gable end walls and horizontal cracks in western wall at roof level were noted in Compressor Room. In Cooling Plant Machinery Room cracks developed along the junctions of the concrete pillars and brick masonry. The air intake towers of the Cooling Plant developed horizontal crack near its base the concrete roof slab of the plant. A clock mounted on a semi-circular iron arch at the old gate of the Henry shaft fell down due to collapse of the stone masonry pillars.

Damage was noted in the Milling Plant area. Vertical cracks had developed in western gable end wall of the hall of Milling Plant and in the wall near roof level at its entrance. One of the conical steel settling tank, diameter 16.5 m and height 3 m, developed a puncture due to tearing of the steel plate, probably along a week corroded zone. The circular masonry, supporting these tanks, developed horizontal cracks indicating rocking of the tank. No damage was noted in the concrete supports of the milling machines. No damage was reported in the steel framework for conveyer belts and other steel structures and pipe lines in this area.

BUILDINGS IN BEML ESTATE

The administrative Building of the Bharat Earth Movers Ltd., a two storeyed R.C.C. frame structure developed cracks in almost all the brick panels (Fig. 20) along their margins with the concrete columns and beams, the horizontal and inclined cracks starting from corners of openings. Some brick columns along door openings were sheared at the top. Diagonal cracks were noted along north-south panel walls. The western end wall moved towards west producing a separation of about 2.5 cms at the second storey (Fig. 21).

Damage also occurred in the factory buildings and residential areas. Wheeled Equipment Assembly Workshop, north-east annexe of Machine shop, Gearshop, Pay Roll Building and Personnel Office in factory area, and residential buildings and other structures in the township were studied. All these structures lie on the western and north-western side of Nundydroog mine.

The factory structures consist of sheds with sloping roofs resting on steel space-frames, supported on 10.5 m high masonry walls of 45 cm thickness. Crane gantries run on masonry walls of pillar and panel type construction. Office spaces annexed with these structures on the ends are in brick masonry with R. C. C. flat roofs. No damage occurred in the steel structures. Cracks in the panel walls and along junction of panel walls with masonry pillars had developed (Fig. 23). The southern high walls (10.5 m) of the Tool

Fig. 11. Stone masonry wall at gable end which suffered extensive damage necessitating its dismantling.

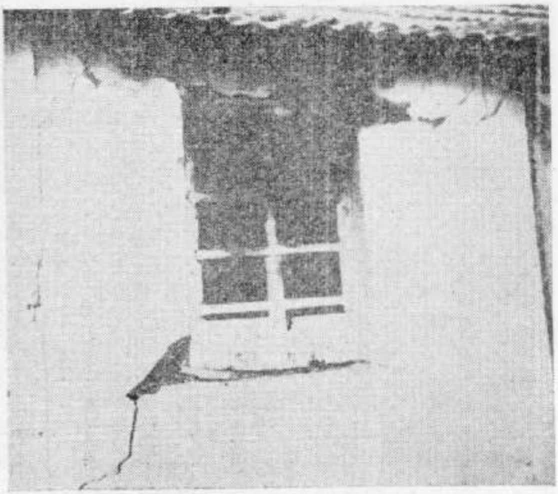

Fig. 13. Extensive cracks from window and door opening propagating towards roof and foundation in masonry wall in House No. 6 in Henry's Masonry block No. 8.

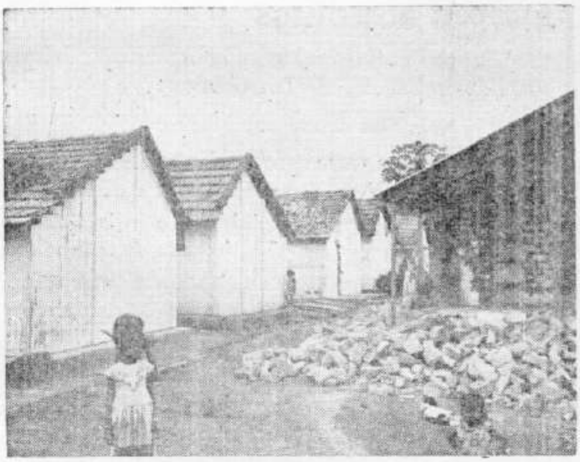

Fig. 12. End wall of stone masonry row house which suffered extensive damage with partial collapse of masonry, necessitating dismantling part of the wall, whereas prefabricated reinforced concrete houses in the left did not suffer any damage.

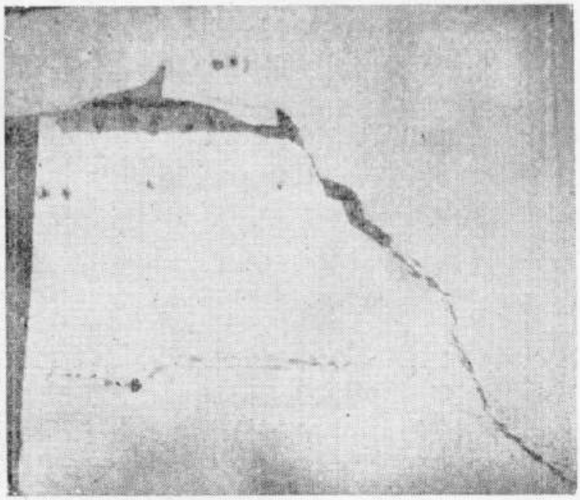

Fig. 14. Damage in the interior wall with cracks propagating from door opening in Kennedy's Muslim lines.

Room and Gear Shop appears to have suffered a slight movement and tilt towards south, as a result of which a continuous crack developed parallel to the wall throughout the length of the wall at the entrance as well as in all the rooms (Fig. 23). Similar damage was noted along the west gable end wall of Personnel Office. Cracks also developed near junction of walls of the shed where these were interlinked with office spaces and other annexes in most of the shops. In general brick wall standing over thick stone masonry walls developed cracks.

Residential quarters in the township mostly consist of single storeyed stone and brick masonry structures with R. C. C. flat roofs. These suffered relatively minor damage as the construction is in cement mortar. However stone masonry walls developed cracks in the interior and along openings. Separation and end wall movements of stone masonry walls was noted in several quarters (Fig. 24). Horizontal cracks developed at roof level. Horizontal and inclined cracks following mortar joints along corners of doors and windows were developed in stone masonry construction. Overturning of loose objects from shelves and almirah was reported. Residences in the officers colony, which are situated about 2 km north-west of Henry's shaft, did not suffer any significant damage. However, minor cracks in plaster were developed in some houses.

In factory area overtoppling and sliding of loose objects was reported. Several heavy machines were laterally moved to the extent of 5 to 10 mm (Fig. 25) towards N 195° to N 210°. Link Boring Machine, weighing about 20 tons resting on twenty 15 cm diameter circular steel pads moved through a distance of 1 cm (Fig. 26) towards N 195°. Multi-spindle Drilling Machine, weighing about 10 tons, resting on twelve similar steel pads moved through a distance of 6 mm toward N 210°. In many machines which were grouted the bolts got loosened, however, no bolt was sheared. Planer Milling Machines weighing 60 and 75 tons which were grouted and leveled over pads were moved towards south by 3 mm and 2 mm respectively and all the foundation bolts got loosened. The friction between the steel pads and the concrete was determined by test at site, and the coefficient of friction was noted to be 0.5. This indicates that the peak ground acceleration during the tremor exceeded 0.5 g.

REPAIR AND MAINTENANCE OF EXISTING BUILDINGS

The following methods of repairs of damage in the buildings were being adopted by BGML after previous rockbursts as well as the November 27, 1971 rockburst.

(i) **Cracks in Masonry Walls :**

(a) If only the wall plaster was affected, the cracks were grooved and the surface replastered;

(b) If the cracks extended into the mortar joints, the mortar joints were raked and replastered;

(c) If the cracks were long and extended through the masonry walls the plaster was removed along them and bonding bricks were put across the cracks at approximate distances of 1 m apart and then replastered; and

(d) If the cracks were many with dislocation of brick or stone involving falling, tilting or bulging of masonry, the affected masonry part was dismantled and rebuilt. In some cases where end gable walls had bulged they were held together by long tie rods. In few cases involving too much shattering of masonry, complete walls were dismantled for rebuilding.

(ii) **Cracks in masonry construction above arch openings :**

(a) If the cracks in an arch were not numerous and extensive, tightening of the key stone and sides was done by jacking, or an steel arch conforming to the inside

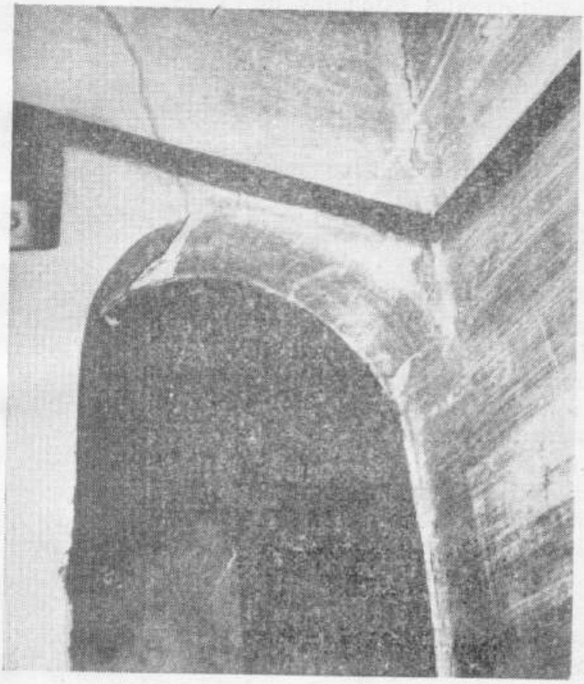

Fig. 15. Damage of masonry arch in cross wall in Henry's masonry Block No. 4, with development of crack along the junction of the main wall.

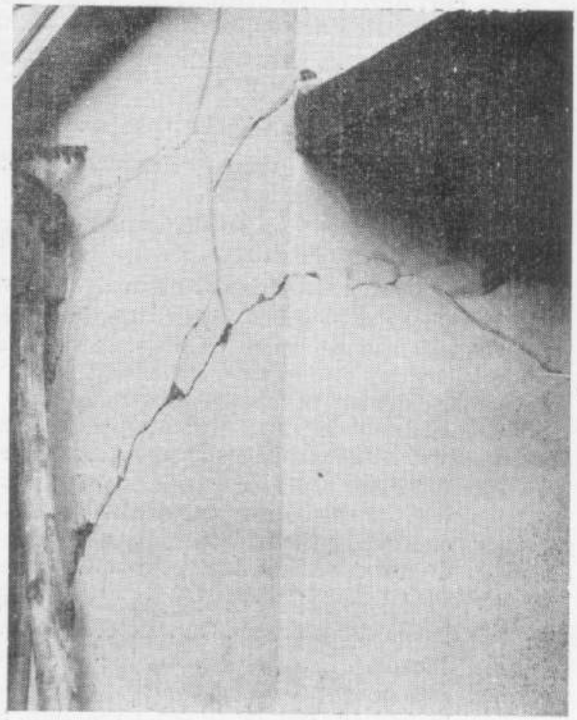

Fig. 17. Development of cracks in brick masonry walls of Gate Clerk Room at Henry's Shaft Gate, which suffered extensive damage. The photograph shows northwest corner of the room from outside.

Fig. 16. Development of cracks in stone masonry north wall of the Lighting Sub-Station in Henry shaft area. Similar cracks developed in other walls of the strurtvre.

Fig. 18. The Watch and Ward Post, at Henry's Shaft Gate in prefabricated reinforced concrete construction, which did not suffer any damage.

curvature of the masonry arch was provided with its sides extending up to the foundation or supported by tie rods at the springing.

(b) If the cracks were numerous the arches were replaced by reinforced concrete lintels.

(iii) **Damage to roof and other parts :**

(a) In disturbed tile roofs, the tiles were removed and relayed and the masonry and concrete ridges if cracked were rebuilt.

(b) Damaged partition walls were replastered or dismantled and rebuilt depending on degree of damage.

(c) Displaced and cracked parapet walls were reset and replastered.

The above methods of repairs are in general satisfactory. As it is not possible to completely safeguard against development of cracks in masonry structures due to their brittle behaviour during severe rockbursts and earthquakes, efforts must be directed to prevent development of major cracks and failure of the walls with consequent collapse of roofs. The following measures adopted in the repairs and maintenance of existing buildings will reduce damage during future rockbursts.

(i) Wherever walls or portions of the walls are to be rebuilt or additional or new walls are to be constructed, L-shaped dowel bars should be introduced at corners connecting the new masonry wall with the old masonry wall so that the corners do not open in future rockbursts.

(ii) Masonry arches existing over large openings should either be supported on the inside curvature as used heretofore or suitably tied by providing tie bars.

(iii) Masonry filler walls in timber or concrete framework should be tied with the frame by providing some form of hold-fasts. In timber frame wire nails projecting out by 10 cm from the framework and embedded along mortar joints can be adopted. Projecting reinforcement bars from the concrete columns and beams could be utilised for tying the walls in concrete frames.

(iv) Wherever ruble masonry walls are to be replaced, they should preferably be replaced with coursed stone masonry or brick walls.

(v) Rubble masonry old houses in dilapidated condition in "mud" or cinder mortar, which invariably develop extensive cracks during rockbursts should preferably be dismantled.

(vi) Cement mortar in 1:6 proportions should be used in place of cinder and lime mortar.

(vii) There are many important structures in the area, like head frames above shafts and their foundations, foundations of hoisting drums and other heavy machines, hospital and elevated water towers in the region. It is essential that detailed analysis should be carried out to check their stability during future rockbursts.

CONSTRUCTION OF NEW BUILDINGS

The following general recommendations are being made for construction of ordinary structures so as to avoid severe damage or collapse, during rockbursts:

(i) Lighter but laterally strong structures will be preferable to heavy and weak constructions. Hence reinforced concrete or steel structures are best. Brick masonry will be better than random rubble stone masonry and cement mortar will be much superior to lime or mud mortar.

(ii) Reinforced cement concrete or steel structures should be preferred for hospital, power house, water towers and other structures of post-rockburst importance.

(iii) For single storeyed constructions, the wall thickness may be kept equal to the length of the masonry unit. For example, when 23 cm (9 inch) bricks are used,

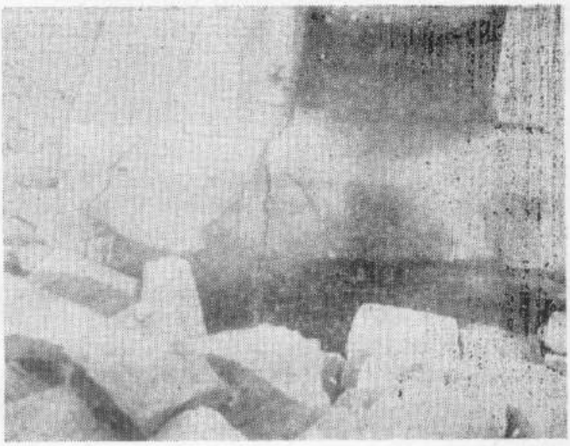

Fig. 19. The concrete foundation of the back brace of the head frame of the Henry's shaft which developed extensive cracks.

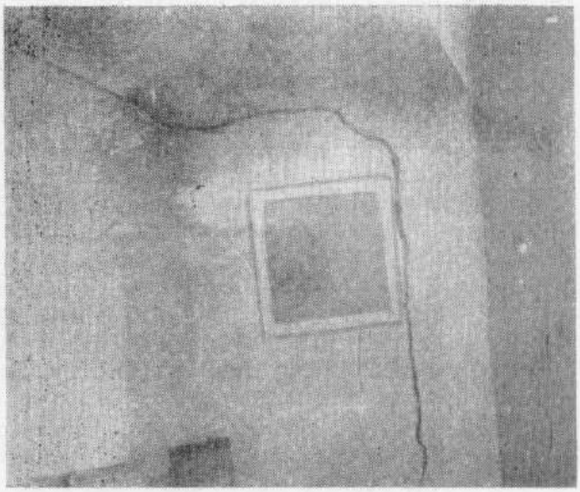

Fig. 21. Movement of the western end wall at the second storey level of the Administrative Building of the Bharat Earth Movers Limited with development of 2.5 to 3 cm. wide cracks in the wall.

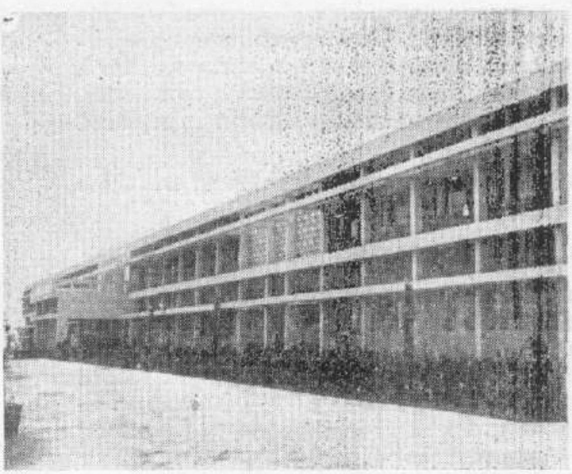

Fig. 20. Administrative building of the Bharat Earth Movers Ltd., a two storeyed reinforced concrete frame structure which suffered damage in the interior brick panel walls.

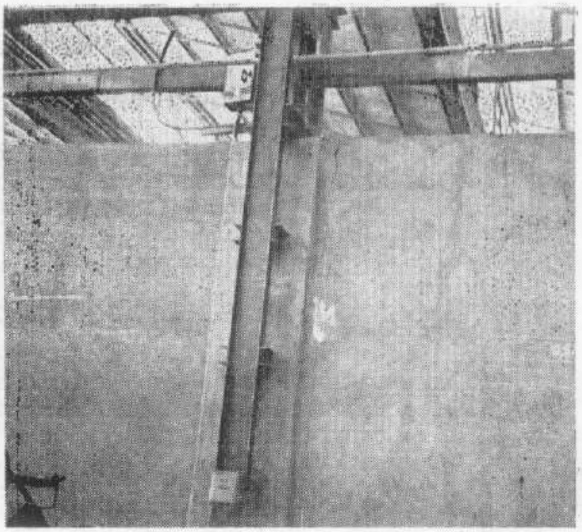

Fig. 22. Brick masonry wall in the Wheeled Equipment Assembly Shop showing vertical cracks near the Junction of brick columns.

the wall thickness may be kept only 23 cm (9 inch); 23 cm (9 inch) wall thickness in FIRST class bricks should be preferred to 38 cm (13.5 inch) wall in 3rd class bricks; and the mortar mix should be minimum of 1:6 cement sand mortar in superstructures. Stone masonry may be used in the foundation upto plinth.

(iv) A reinforced concrete band (ring beam) over all outer and inner walls should be introduced at lintel level in all types of masonry construction.

(v) Such a ring beam is not necessary at the plinth level (above basement) unless the plinth height is more than 60 cm (2 ft) above ground level. Instead of the plinth band, damp proof course of about 20 to 25 mm in thickness may be provided at the plinth level.

(vi) If the strength of cement bricks is equal to that of the first class bricks or more, they could be made in lengths of 20 cm and used instead of first class bricks. In that case the thickness of load bearing walls may be kept as 20 cm. Such cement bricks should preferably have rough surface for proper bonding with cement mortar.

(vii) Prefabricated reinforced concrete column-panel construction for single storey labour quarters would be better in relation to masonry construction. Comparing the relative merits and demerits of the two, it is noted that the prefabricated reinforced concrete column panel construction will be most suitable from rockburst point of view. These will require practically no maintenance effort later due to rockbursts. Moreover this types of houses will be damp proof, provide much larger living area for the same given plinth area (95% in precast post-panel construction against 75% for 23 cm (9 inch) brick-wall construction) and will be safe against termites. However, as the panel wall on the exterior may be cold during winter and hot during summer, the design may be modified to have double wall panels on the exterior of living rooms as shown in Fig. 27. It is recommended for adoption in future construction in such areas, which will provide insulation from exterior heat and cold and additional strength to the structure.

(viii) In case of masonry construction it would be impracticable to completely rule out the development of cracks in the walls during future rockbursts. The provisions as described in (iii) to (vi) above if incorporated in such construction will provide adequate safety against severe cracking or collapse. Masonry chimneys projecting above gables, are sometimes constructed in masonry structures. Such chimneys and other projections are vulnerable to damage during rockbursts, and they should preferably be avoided. Masonry chimneys should be replaced by pipe chimneys at least above the roof level.

(ix) Heavy roofs should be avoided. Asbestos cement sheets are brittle and these often crack resulting in fall of rooftiles and injury.

INSTRUMENTS FOR RECORDING GROUND MOTION

The design of burst resisting structures need data on the intensity and duration of strong motion characteristics of the ground during tremors resulting from rockbursts and other causes. Such data is obtained from accelerograph records. No strong motion recording instrument have yet been installed around BGML mines which could record the accelerations during this rockburst or earlier events to evaluate design parameters. The sliding of the machines in BEML indicate that the peak ground accelerations during 27 November 1971 rockburst exceeded 0.5 g. The movement of the hoist block lying idle in the foot wall gap, between pillars 22 and 24 at 4500 level through a distance of one metre in the Nundydroog mine indicates even higher peak acceleration.

It is essential that for proper design of structures, strong ground motion recording instruments should be installed in the region. Suitable accelerographs, with one vertical

Fig. 23. Development of a crack if the floor near the 10.5 m high sourthern wall of the Tool Room Shop of Bharat Earth Movers Ltd. which propagated parallel to the length to the wall in all the rooms.

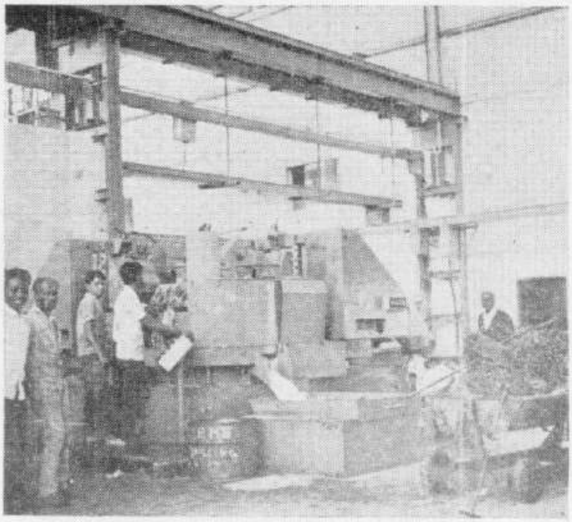

Fig. 25. Link Boring Machine, 20 tons in weight, which was moved by 1 cm. towards south.

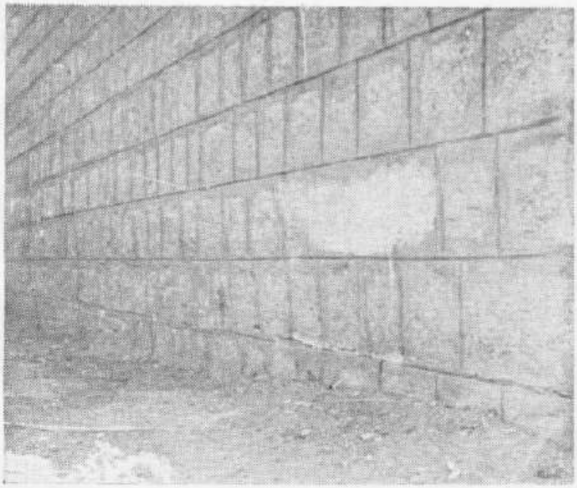

Fig. 24. Separation of end wall of a Type I quarter in Bharat Earth Movers Limited township, which produced a horizontal crack at the plinth level.

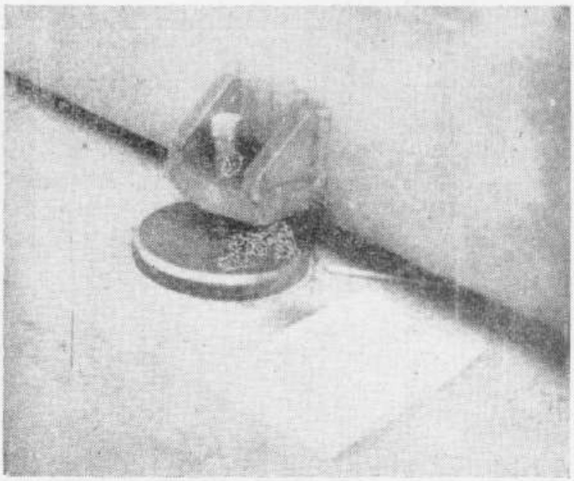

Fig. 26. Displacement of one of the steel pads supporting Link Boring Machine shown in figure 43. Shaded area shown was exposed after resetting of the pads.

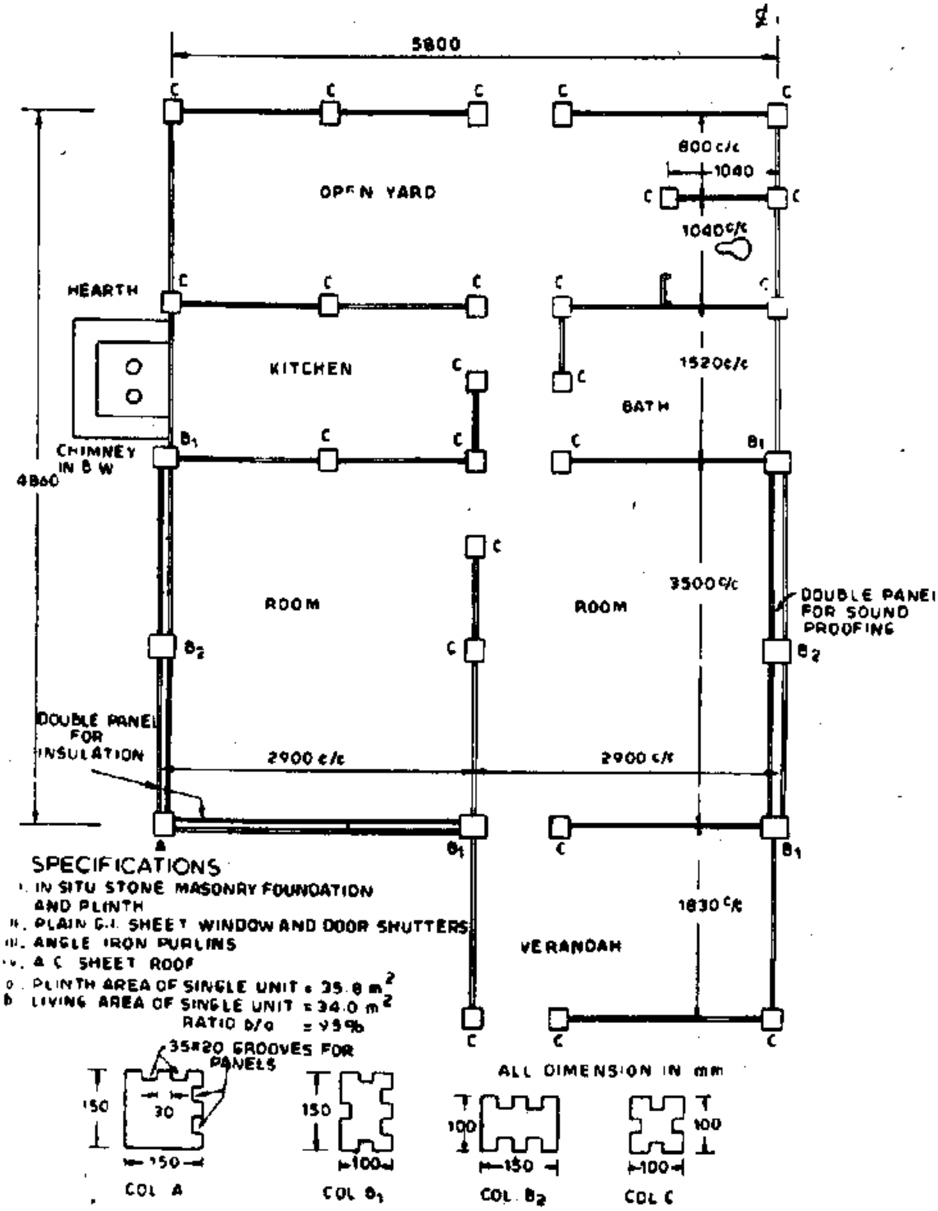

Fig. 27. Prefabricated post panel construction.

and two horizontal components, be installed to measure ground accelerations in the area, one at the surface in the centre of the mining area and one each inside the mine in the levels at mid-depth and at the bottom. In order to have greater instrumental coverage of strong motion data in the region Structural Response Recorders should be installed at the ground surface and in the underground mines at 300 m (1000 ft) interval in the levels. These recorders are dynamic models of structures and record the dynamic response of the structure due to ground motion which the recorder is supposed to model. Thus they provide the integrated effect of the ground motion and geologic condition at the site and give data for direct applications for the design of the type of structures existing in the region. The recorders therefore should have periods from 0.4 to 0.7 sec the damping from 5 to 10% as that of the structures to be located on the surface and underground. It would also be desirable to record the minor tremors in the region using high sensitivity short period seismograph having a magnification of the order of 10^5 to determine the predominant period of ground motion.

Data obtained from above instrumentation will help in evaluating design parameters for dynamic design of structures from the characteristics of ground motion expressed by response spectrum curves indicating maximum dynamic response of idealised structure with different damping and vibration characteristics during tremors due to rockbursts and other causes.

CONCLUSIONS

The following conclusions are drawn based on the survey of the damage due to November 27, 1971 rockbursts in the area carried out by the authors.

1. The rockbursts seem to have been caused by rock fracture due to stress concentration near the contact zone of dolerite dykes with wall rock between 3600 and 4500 level involving a rupture 270 m in length with displacement of 15 mm.

2. The seismic waves generated by the main rockburst show high acceleration. The seismogram recorded for the event at Hyderabad give a magnitude of 4.6 (surface waves). The peak ground acceleration at BEML factory was at least 0.5 g. Elsewhere it may have been greater. For instance inside the mine at 4500 level, the peak acceleration must have been much more. It is, however believed that as the time base of acceleration pulse must have been small and the duration of strong ground motion was not large ground structures and mine workings escaped major damage and collapse.

3. Lighter in weight but stronger against lateral forces forms the basis for construction of buildings to resist rockbursts in the region. Heavy construction in random rubble stone masonry and use of weak mortars like lime, cinder or mud is not suitable. For low cost smaller buildings for labour colonies, use of prefabricated R. C. post-panel construction is recommended. For larger construction reinforced concrete or steel frame structures will be desirable.

4. For proper recording of strong ground motion during future rockbursts, installation of accelerographs is suggested, which would permit construction of response spectra for various natural periods and damping values of different types of structures. This will also provide data for carrying out dynamic analysis of important structures. For direct measurement of structural response of simple idealised structures installation of structural-response-recorders will provide greater instrumental coverage and additional strong motion data in the region.

5. Rockbursts are not natural hazards. The development of the mines and planning and design of the different working areas should endeavour to avoid stress concentration in the rock masses which could lead to sudden explosive failure, and efforts should be made to continuously moniter the stress field around openings for the control and prevention of rockbursts.

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