5.6.2 Effect of restraint on Georgedale bricks

Two Georgedale bricks fired at 1030 ℃ were loaded to 10 MPa and placed in the fog room. Their expansion under this quite high load are shown in Figures 34 and 35. The thick lines show the longitudinal expansions and the thin lines the transverse expansions. The longitudinal expansions against the load were very similar but the transverse expansions differed. This illustrates that to get information on expansion against restraint at least two if not three of the same bricks should be loaded under the same conditions. Such more accurate information however would have little meaning in preactice as bricks from a firing in one kiln would be fired at a range of temperatures and their properties would differ by far more than the differences shown on Figures 34 and 35. A general trend has been sought, thus on occasions, because of the expense of loading frames, only one brick was loaded under a particular set of conditions but mostly two bricks were loaded as can be seen on Table 8.

The difference in transverse expansion on these Figures was probably due to some internal vertical cracks in the one brick. A number of bricks after firing had to be discarded because of the development of visible cracks which would have affected results required for comparison purposes.

Figures 36 and 37 show the expansion of two Georgedale bricks fired at 1030 ℃, loaded to 0,7 MPa and exposed to the weather on the roof. Their expansion patterns are seen to be almost identical for the 250 days they are compared. Their expansions are also almost identical to those of the unloaded Georgedale bricks fired at 1030 ℃ and exposed on the roof. The loaded bricks also reduced in length with the onset of the cold dry weather and increased in length when the wet warmer weather started. See Figure 38. The flat portion

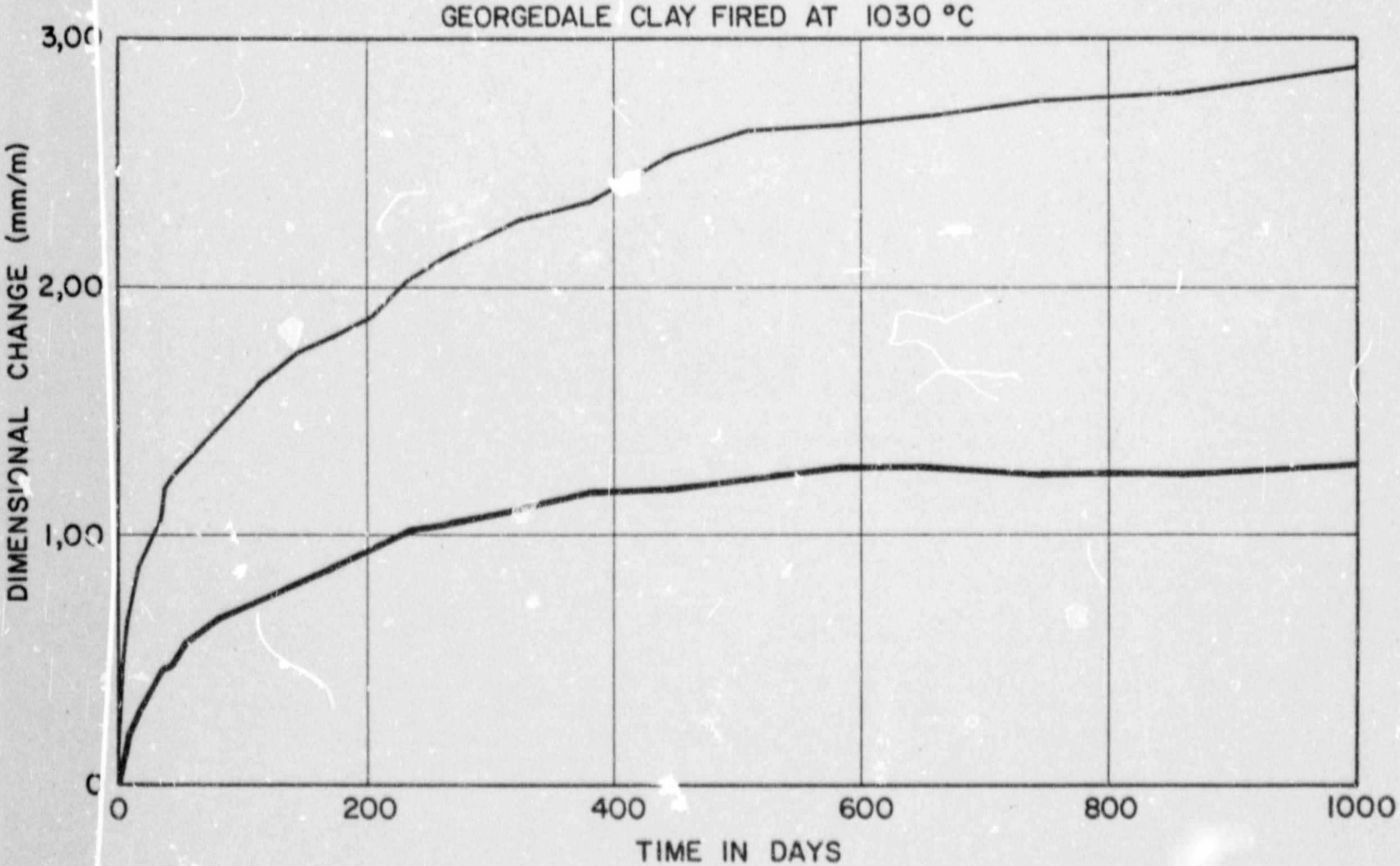

FIGURE 34

Brick in humidity room - load 10 MPa (1450lb/in²)

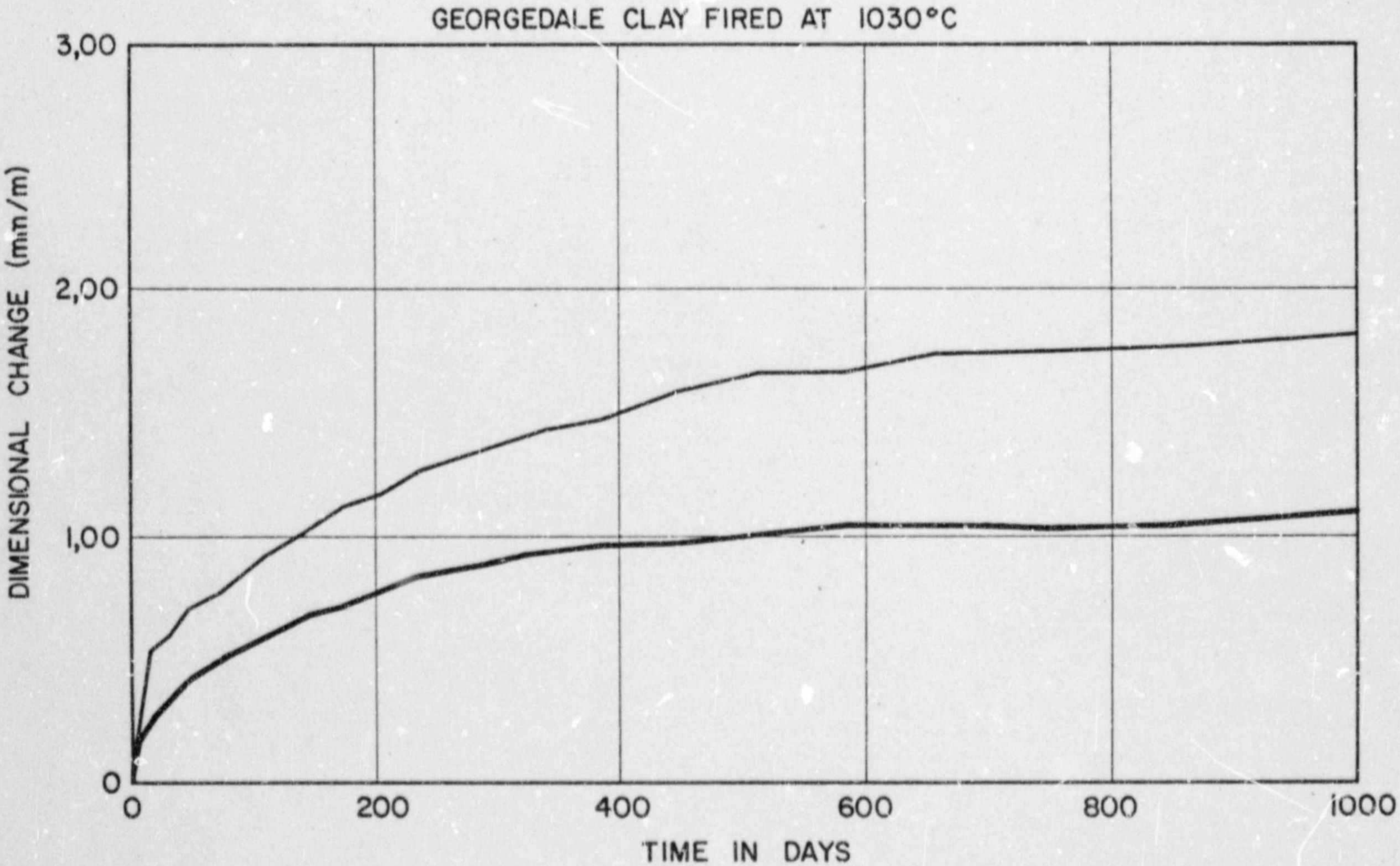

FIGURE 35

Brick in humidity room - load 10 MPa (1450 lb/in^2)

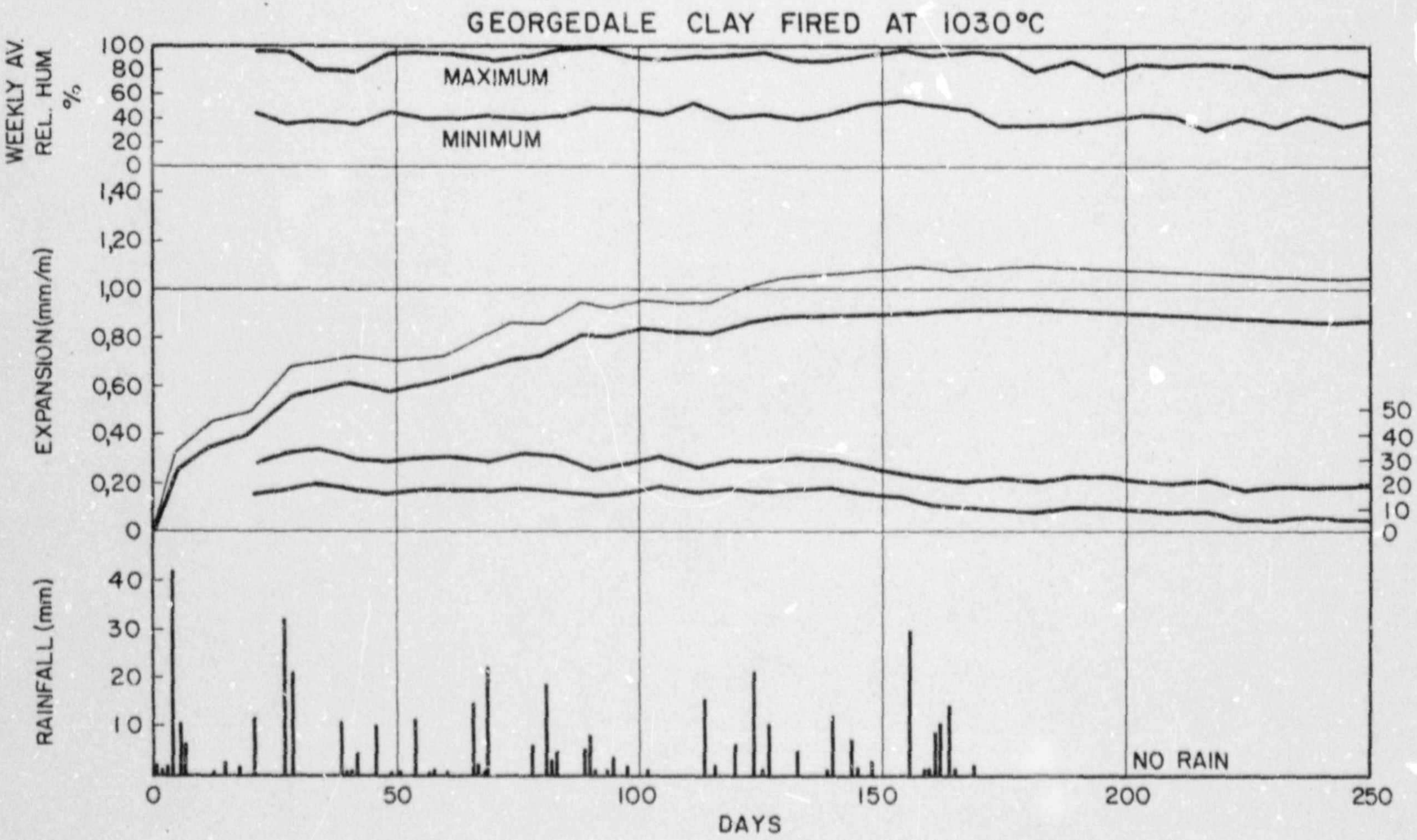

FIGURE 36

Brick exposed on roof - load 0,7 MPa

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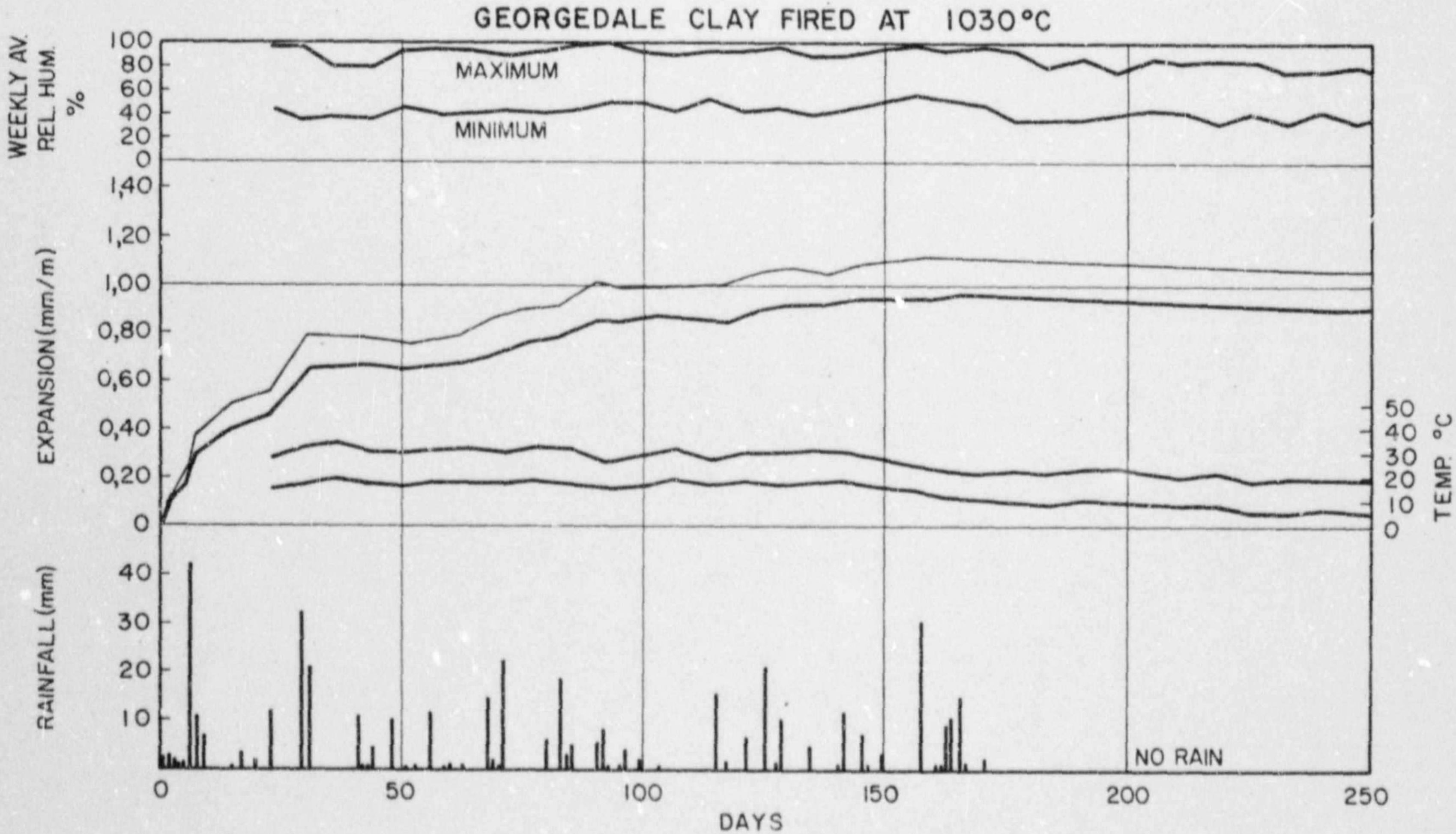

FIGURE 37

Brick exposed on roof - load 0,7 MPa

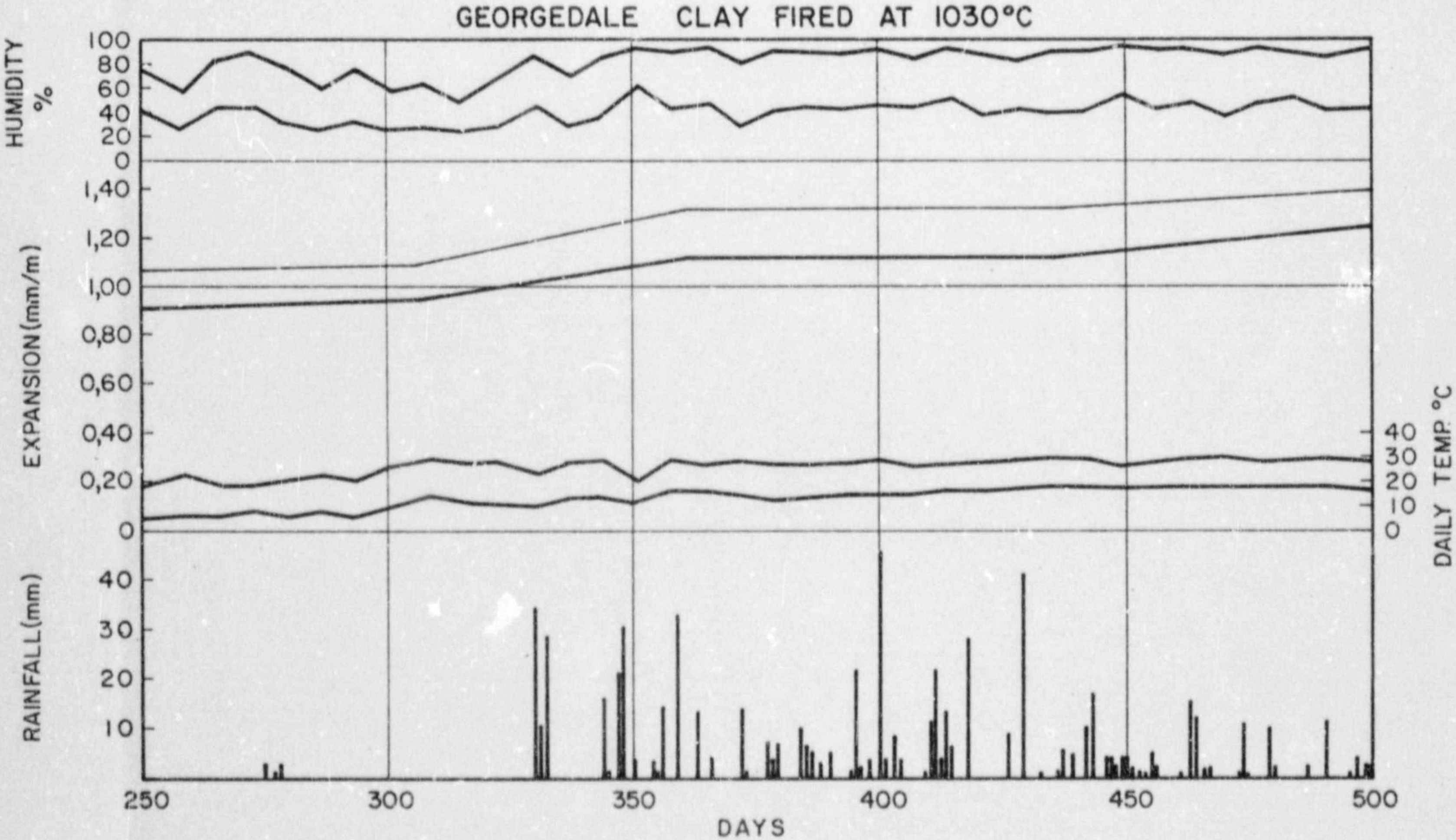

FIGURE 38

Brick exposed on roof - 0,7 MPa (101LB/IN^2) load of the graph during the height of a particularly wet period was probably due to the reduced number of hours of sunshine and thus less radiant heating of the bricks in spite of the warm air conditions shown on the graph. It is seen that when the rain reduced after 450 days and the minimum temperatures increased there was again an expansion. The behaviour of the loaded and unloaded bricks is compared on Figure 39 where the closeness of their behaviour is demonstrated. When a brick is not loaded both the transverse and longitudinal moisture expansion strains are similar, but when loaded the transverse strain becomes higher.

Three Georgedale bricks fired at 1030 °C were exposed in the fog room under three loading conditions, viz. not loaded and loaded to 1,5 and 10 MPa. These bricks are compared on Figure 40. It is surprising that the unloaded brick had such a low initial expansion when compared with the loaded bricks but this was an average of the expansions of three bricks and the 10 MPa the average of two bricks. Although the loads did not apparently do much to prevent expansion, the increased expansion of the unloaded brick on the log-time scale after 100 days appears to have been suppressed to a large extent in the loaded bricks.

5.6.3 Effect of restraint on Bellville bricks

Bellville bricks fired at 1020 °C were placed in the fog room under four different compressions, viz. nil load, 0,7 MPa, 1,5 MPa and 10 MPa. Figure 41 shows the expansions of these bricks. The higher the compression the less the expansion was. The slight discontinuities in the curves between 200 and 300 days were because of a temporary breakdown of the machinery controlling the temperature and humidity of the humidity room. This information is also presented on Figure 42(b) where expansion is plotted against

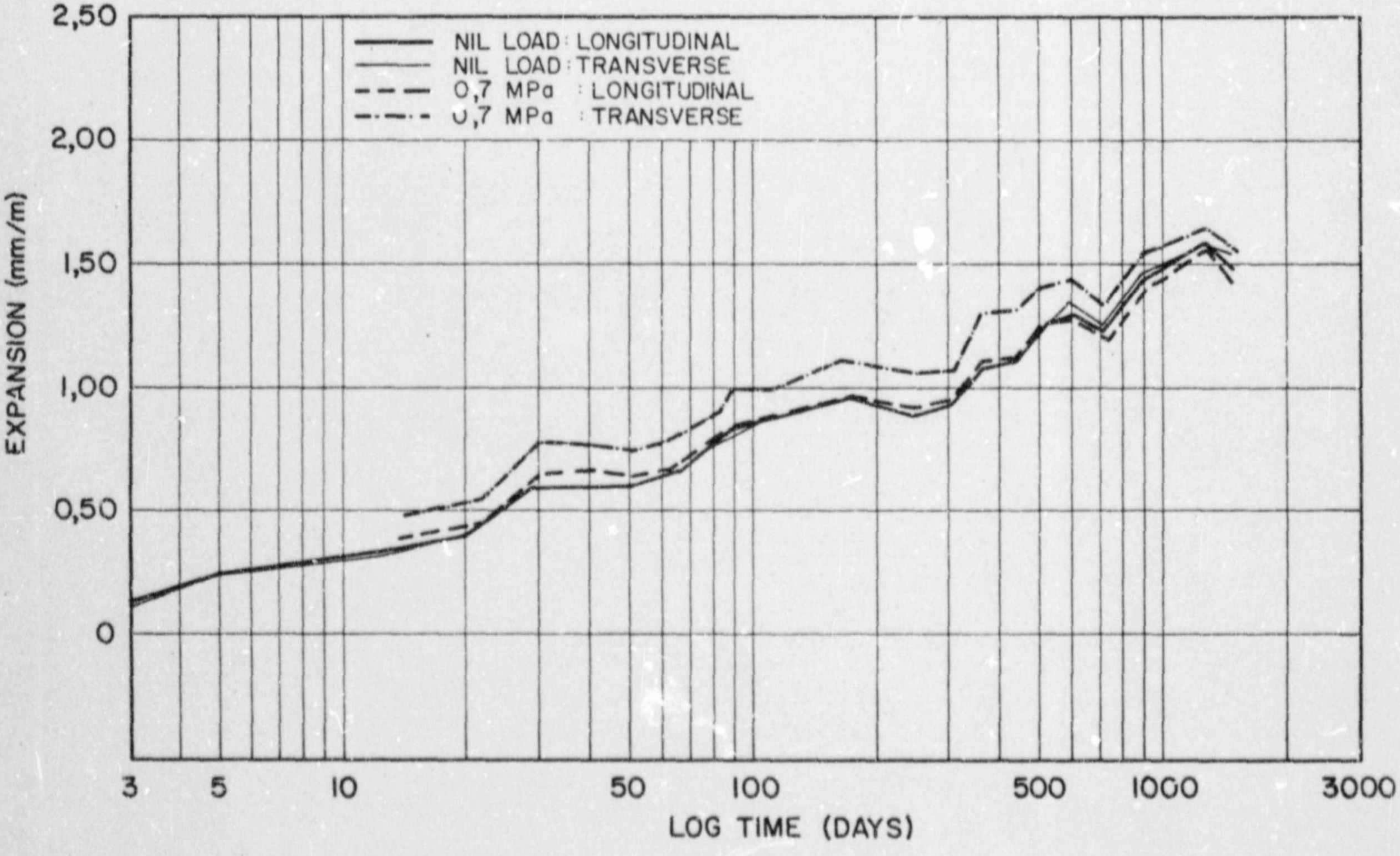

FIGURE 39

Expansion of Georgedale clay bricks fired at 1030°C on roof

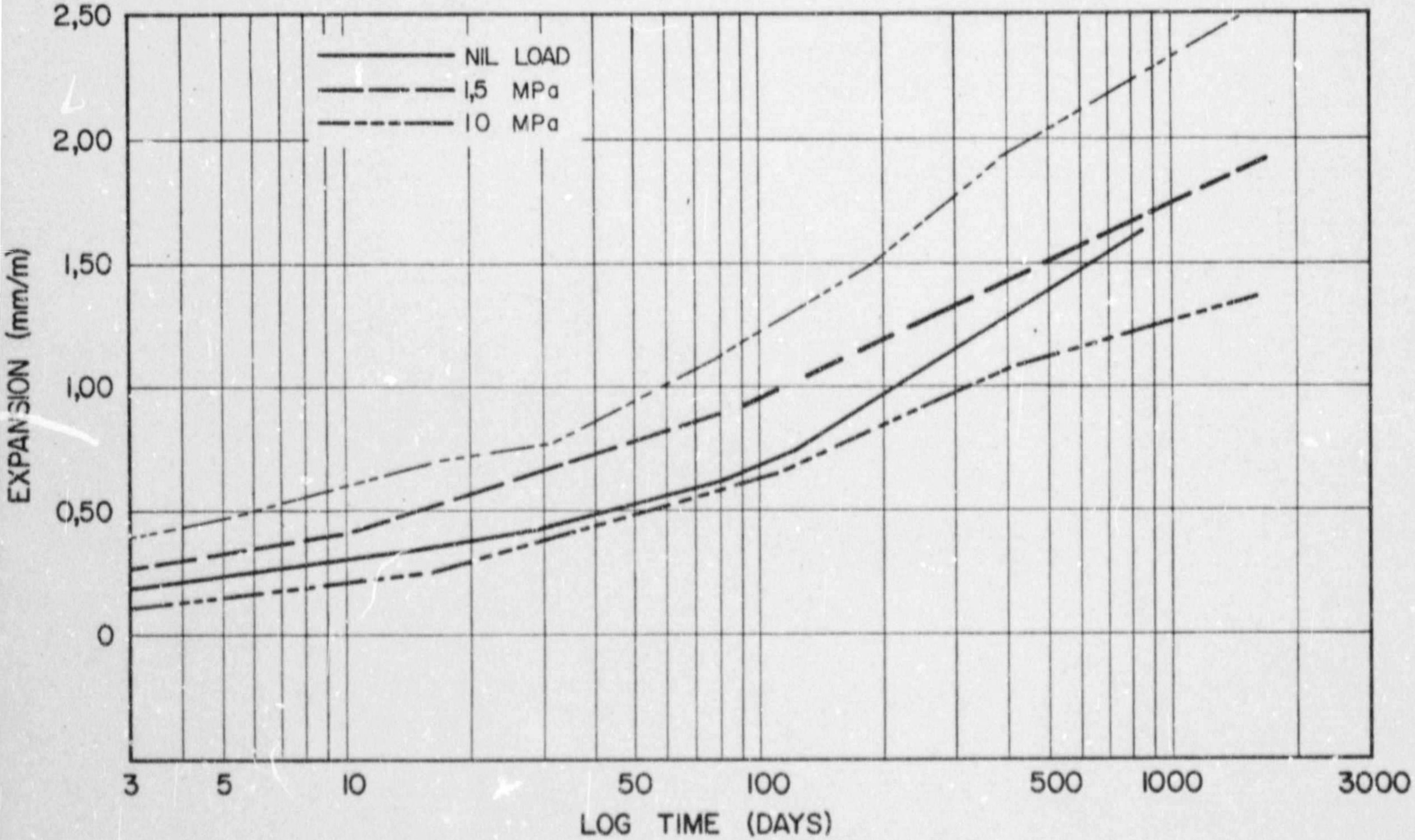

FIGURE 40

Georgedale clay bricks fired at 1030°C: different loads in fog room.

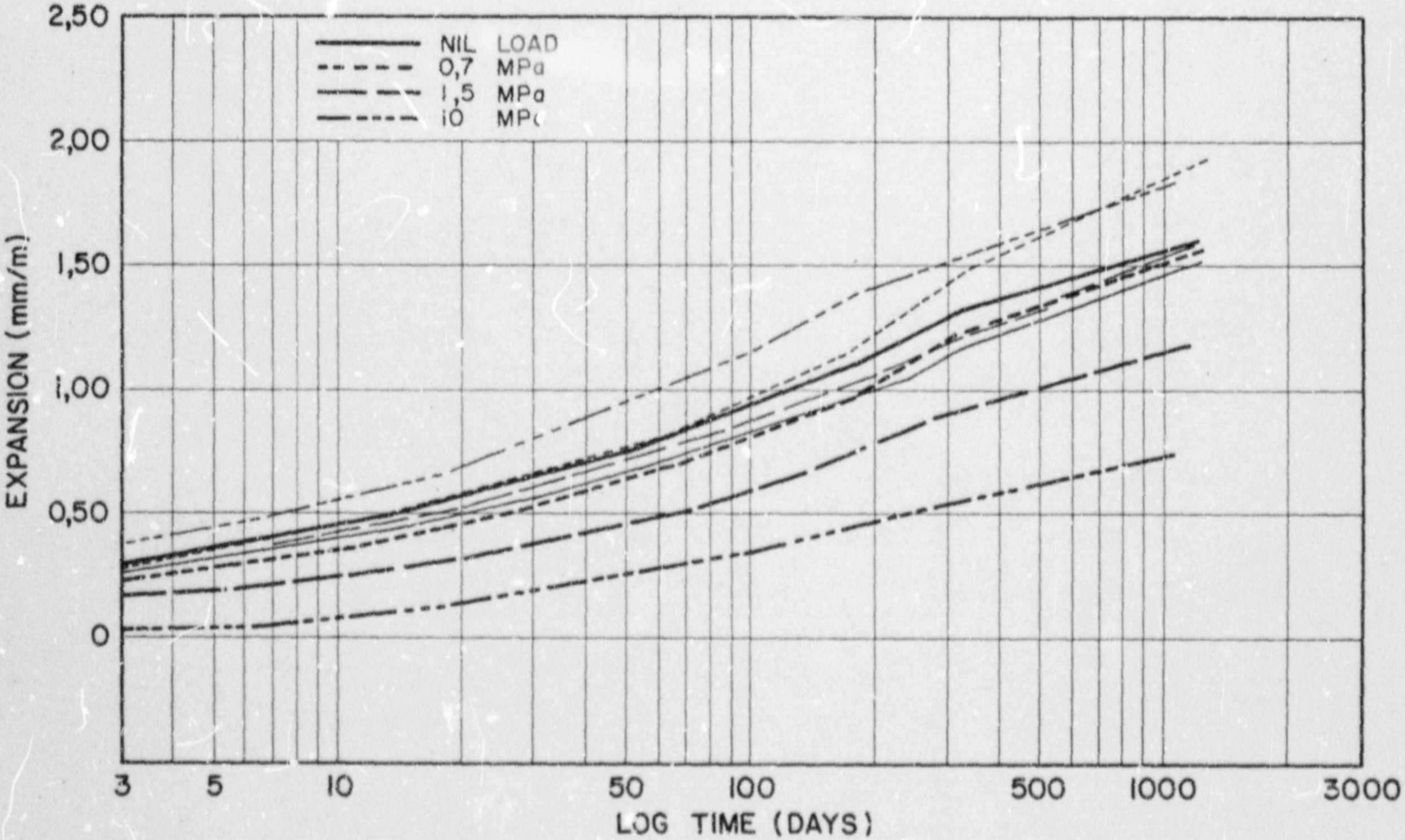

FIGURE 41

Bellville clay bricks fired at 1020°C : different loads in fog room

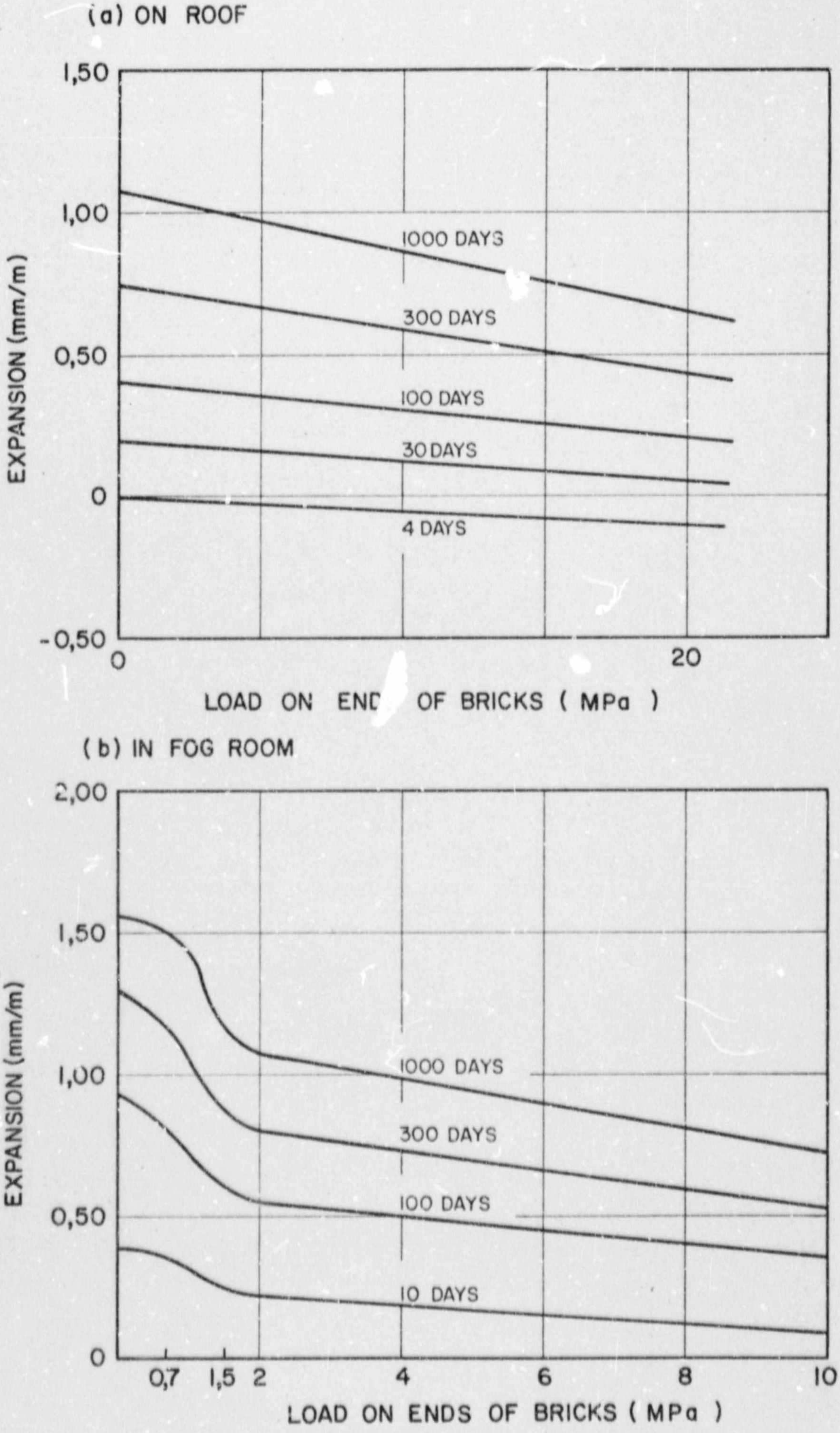

FIGURE 42

Expansion of Bellville bricks under load the load on the ends of the bricks for different periods of exposure in a moist atmosphere. For light stresses up to 2 MPa there is a reduction of expansion of up to 40% over the first 300 days, but this reduces to about 30% at 1000 days. At a compression of 10 MPa there is a reduction of expansion from 80% at 4 days to 55% at 1000 days.

Bellville bricks fired at 1020 ℃ were exposed on the roof within a day of each other under four loading conditions, viz. nil load, 0,7, 1,5 and 20 MPa. Figures 43 to 46 show the first 250 days expansion plotted against time. Information is given on these graphs on daily rainfall, maximum and minimum daily temperatures and maximum and minimum daily relative humidities. The effect of the weather conditions on the expansions can be seen. After relatively low expansions during the dry period just after exposure, a sharp increase in expansion took place as soon as the bricks were wetted by three consecutive good rainfalls and throughout the warm wet periods the expansions continued at a slightly decreasing rate. The initial reduction in length was due to the temperature of the laboratory in which the zero readings were taken being warmer (22 ℃) than the conditions on the roof when readings were taken early the next morning (8 ℃). In the case of the brick stressed to 20 MPa it was subject to a noticeable creep over the first few days and then a slower creep during the next 20 days, after which the expansions became greater than the continuing creep. The bricks without loads and the bricks with loads of 0,7 and 1,5 MPa expanded about the same amount so that these loads had little effect over the first 250 days, but the brick stressed to 20 MPa had its expansion considerably reduced, being at 250 days about 40% of that of the bricks without loads, but if the obvious creep is allowed for the expansion is 55%. Again the marked effect of load on the transverse expansions can be seen, being the same as the

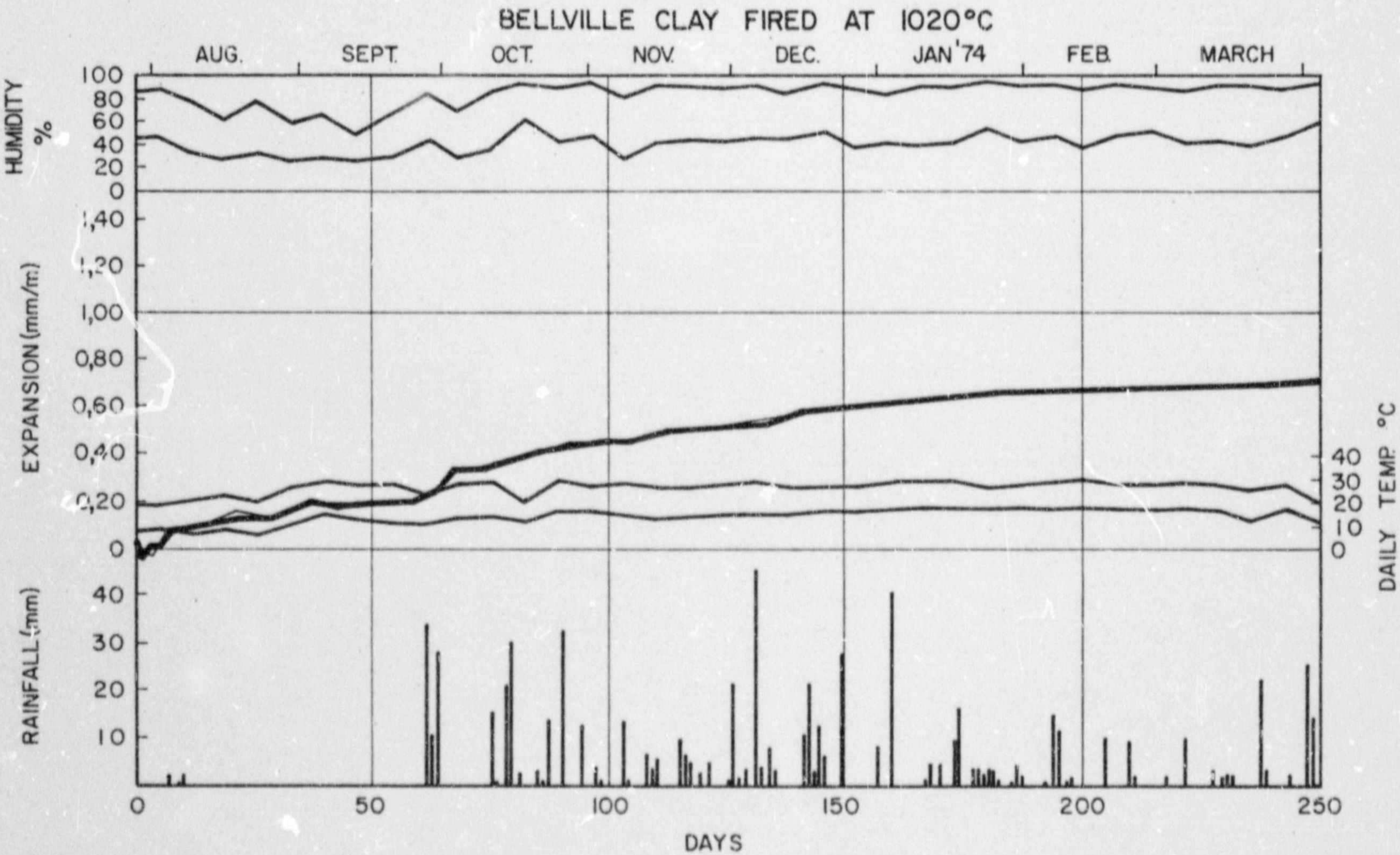

FIGURE 43

Brick exposed on roof - no load

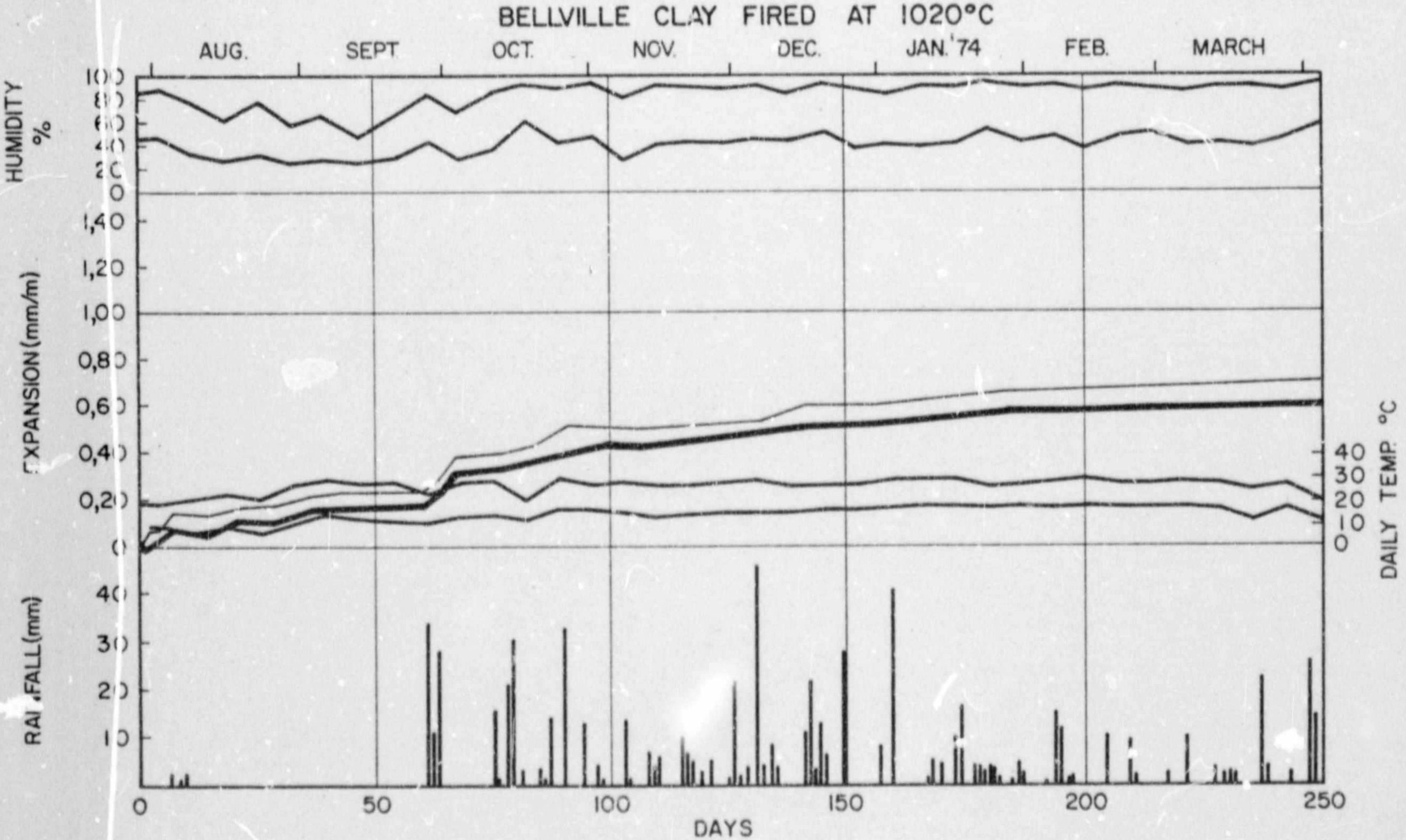

FIGURE 44

Brick exposed on roof - 0,7 MPa load

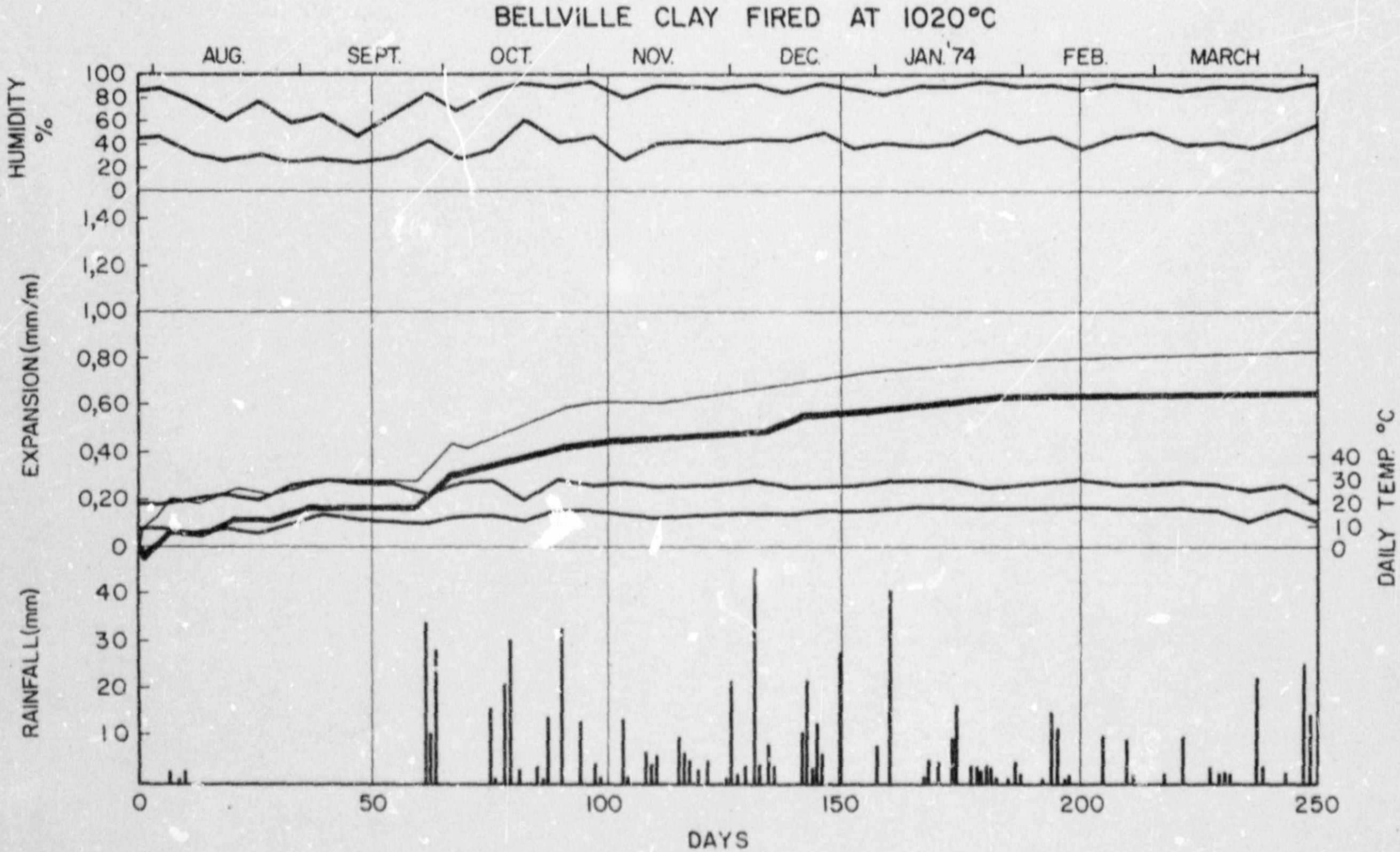

FIGURE 45

Brick exposed on roof - 1,5 MPa load

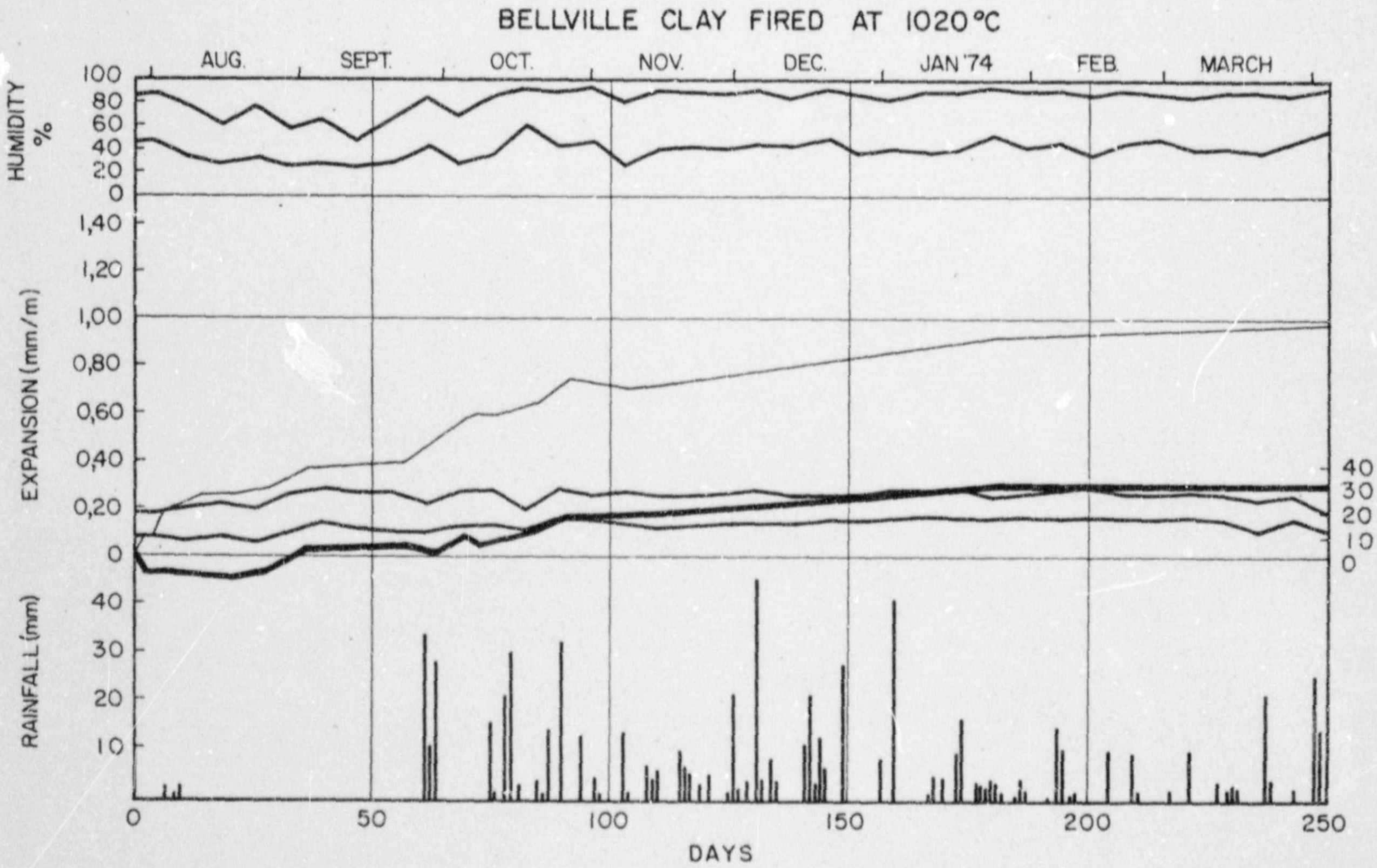

FIGURE 46

Brick exposed on roof - 20 MPa load

longitudinal expansion under nil load and becoming increasingly greater as the loads increased.

The above expansions were plotted against log time on Figure 47 and the effect of cold dry periods can be clearly seen by the dips in the graphs. On Figure 42(a) the expansion has been plotted against the stresses in the bricks but the bricks loaded to 0,7 and 1,5 MPa have been ignored because of the closeness of their expansions to those of the unloaded bricks and because the 1,5 MPa stress caused less restraint on the expansion than the 0,7 MPa stress, an unlikely state of affairs. At 1000 days the heavily loaded brick had expanded 70% of the expansion of the unloaded brick. Thus high restraint on the Bellville bricks has only a small effect on the expansion. In other words under stresses close to the failing stresses the bricks continued to expand a large amount as is shown on Figure 48. The two loaded bricks had expanded very similar amounts up to 100 days but the initial transverse expansion of the one brick was very high and after 30 days started increasing so rapidly that it would have failed if it had not been removed from the frame. This indicates that the bricks were loaded close to their long-term ultimate strength.

5.7 Conclusions

It has been shown that structural restraint is not likely to restrain expansion sufficiently to prevent damage being caused by expansive brickwork. If restraint is imposed, high stresses will develop in the brickwork because of the elastically suppressed expansion and the bricks in a wall might crush. This has been shown both by the laboratory tests and by field observation.

The stresses developed in a restrained brick wall will be most complicated. In factory kilns bricks are subjected to a range of firing temperatures depending on how close they are to the heat source, how much they are screened from direct radiation by other bricks and the length of the soaking period at the firing temperature. Although the well-fired bricks

might / ....

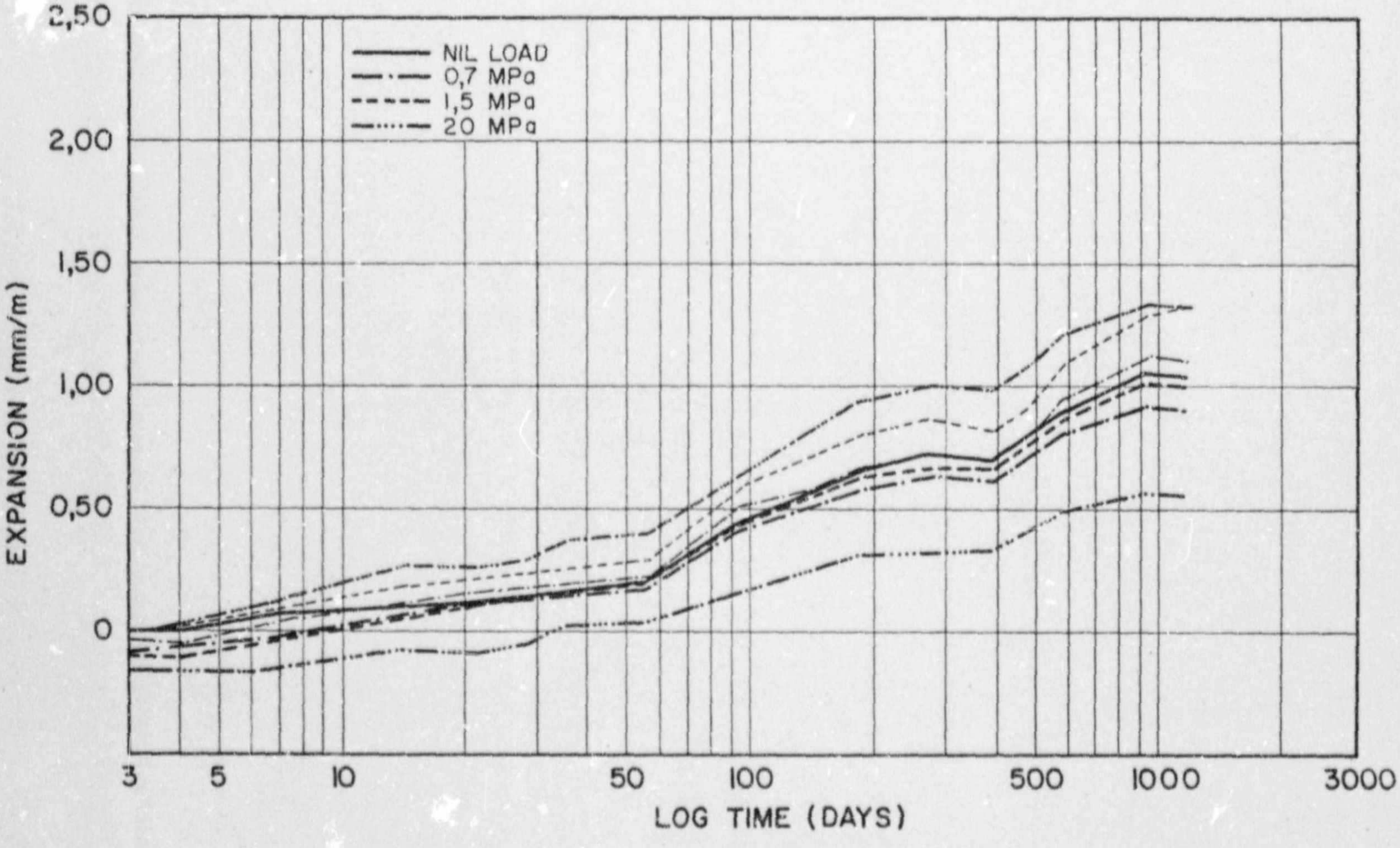

FIGURE 47

Bellville clay bricks fired at 1020°C: different loads on roof

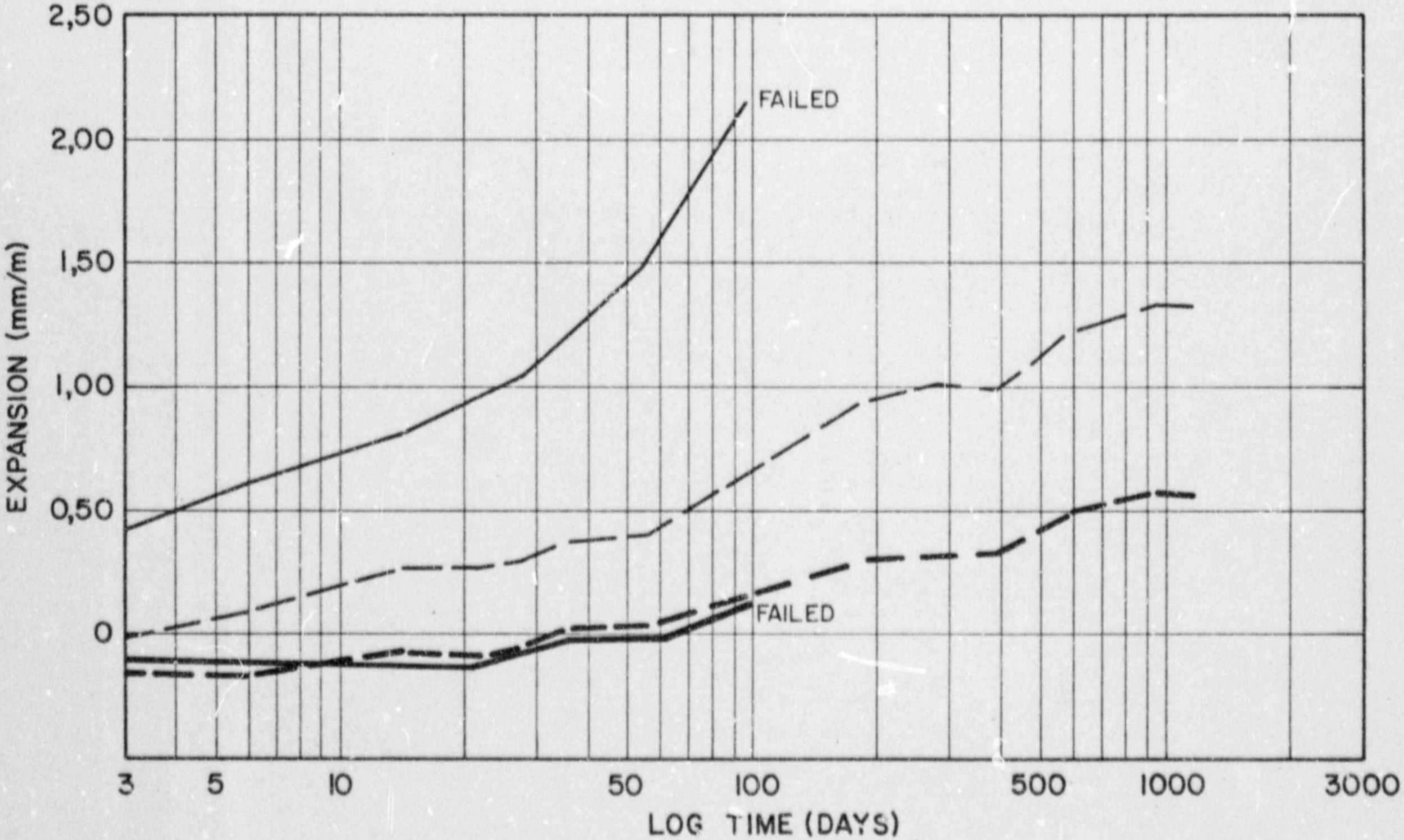

FIGURE 48

Expansion of Bellville clay bricks fired at 1020°C: load 20 MPa on roof might be hand sorted out of each batch, to be sold as engineering bricks, there will still be a range of firing temperatures in any load of building bricks as delivered. Bricks fired at the temperature that gives maximum moisture expansion will expand more rapidly than other bricks, so that initially these bricks will have higher compressive stresses induced in them. However, if a brick wall undergoing moisture expansion is restrained, an overall average compression will be developed in the wall, but individual highly expansive bricks will be under a higher compressive stress than the wall as a whole and therefore such bricks could crush earlier than would be expected from the overall average compressive stress in the wall.

Expansions over 20 and 55 years that have been predicted from the graphs are given on Table 9; the wide variation of expansions can be seen.

TABLE 9 Predicted moisture expansion of bricks

Type of bricks	Exposure condition	Expansion mm/m	
		20 years	55 years
Light-fired (1000 °C)	Fog room	1,5	1,6
Medium-fired (1030 °C)	Fog room	2,0	2,3
Well-fired (1090 °C)	Fog room	0,8	1,2
Bellville (1020 °C)	Fog room	2,15	2,35
Bellville (1020 °C)	Roof	1,6	1,7
Georgedale (1030 °C)	Fog room	2,7	2,9
Georgedale (1030 °C)	Roof	2,1	2,2

The predicted expansions of the non-loaded Bellville bricks on the roof after 20 years and 55 years were equivalent to the expansion (Figure 41) of the non-loaded Bellville bricks in the fog room after 1000 days and 1500 days respectively, whereas the Georgedale bricks would take about 2100 days and 2800 days (predicted from Figure 40) in the fog room to expand to the predicted 20 years and 55 years expansions respectively. This shows that a standard test based on short-term accelerated expansions will not give accurate predictions of brickwork expansions in an actual building, because different clays will probably have different relationships between short-term and long-term expansions.

These predicted expansions will again be considered in Chapter 7.

CHAPTER 6

ANALYSIS OF CRACK IN BEAM TO COLUMN JOINT

6.1 Description of Building and Cracks

A three-storey industrial building in Cape Town was observed to have cracks at the junction of the corner columns and the beams carried by them. From the cracking patterns shown in Figures 49, 50 and 51, it was assumed that the cracks had been caused by expansion of the brick walls on the beams. It was decided to analyse one beam to column joint.

The building, a portion of which is shown in Figure 52 is a reinforced concrete frame building with brick infilling panels. The building stands on the corner of two streets and the external walls facing onto these streets consist of brick walls about half the height of and between the columns of each storey with a continuous band of fenestration from the top of the brick walls to the underside of the concrete beams above. The two external walls bounding other properties are brick infilling walls in the concrete frame with a few small windows let into the walls on the upper storeys.

The building is occupied by one manufacturer and each floor is virtually one large open space except for enclosed staircases, a lift and a couple of offices which are situated in diagonally opposite corners of the building. The corner at the junction of the streets not being one of these corners; just inside it is part of the open space. Only the ground and first floors were inspected. The activity was considered light industrial, in that metal fasteners and other cold-bent thin metal objects were being made. Machines were small and spaced well apart. The boxes into which the small parts were being placed were not stored on either of these floors and the impression was gained that the parts were being sent

out by / ....

FIGURE 49. Crack at top of ground floor at corner of streets.

FIGURE 50. Cracks in column at top of brick wall.

FIGURE 51. Cracks at another corner.

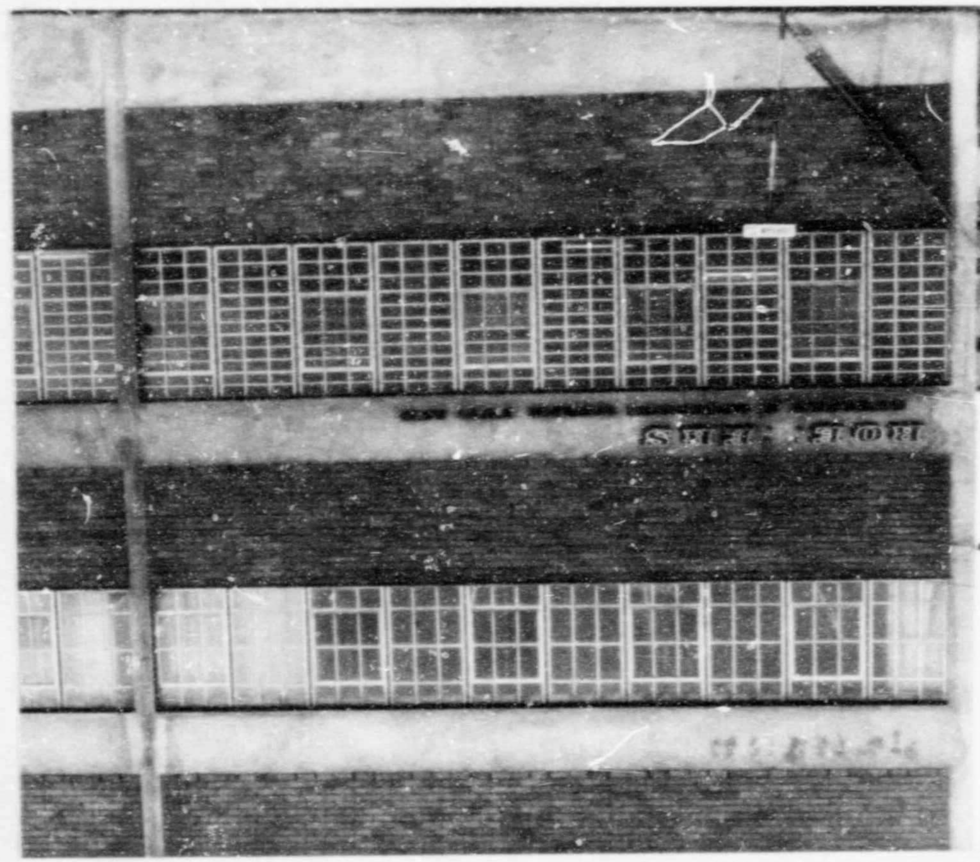

FIGURE 52. Portion of building analysed.

out by truck on a continuous basis. There was a small quantity of unworked material near each machine. On the day of the inspection there were quite a few machines standing idle. The actual superimposed load on the floors was estimated at 2 kN/m^2.

The dimensions, in centimetres, of the reinforced concrete frame and infilling walls at the corner to be analysed are given in Figure 53. The corner is marked B on the plan and G-G on the elevation. Centimetres are used for the dimensions because there is a limitation on the number of digits after the decimal point that can be used in the finite element computer program.

The external concrete beams and columns had been plastered and part of the plaster had been replaced during repairs to the junction between the corner column B and the beam BC. Whenever the surface of the beam or column is referred to, it means the surface of the plaster at that place on the beam or column. The first cracks occurring in the surface of a concrete element will usually crack the plaster in the same position, but, if movement takes place in the crack which loosens the bond between the plaster and underlying concrete, subsequent cracks will not necessarily be duplicated by those on the concrete surface.

The visible cracks at the junction of column B and beam BC are shown in Figure 49. Between the brick wall and the beam a fine crack occurs for most of the distance from column B to column C. This crack starts widening about 2 m from column B at the interface between the brick wall and beam and increases in width as it progresses towards the corner. About 600 mm from the corner, the crack starts curving downwards until it becomes almost a vertical crack in the column just below the bottom of the beam. Similar cracks were observed at other beam to column junctions at corners. The vertical part of the crack tends to be 100 to 130 mm from the corners. A further crack in the concrete

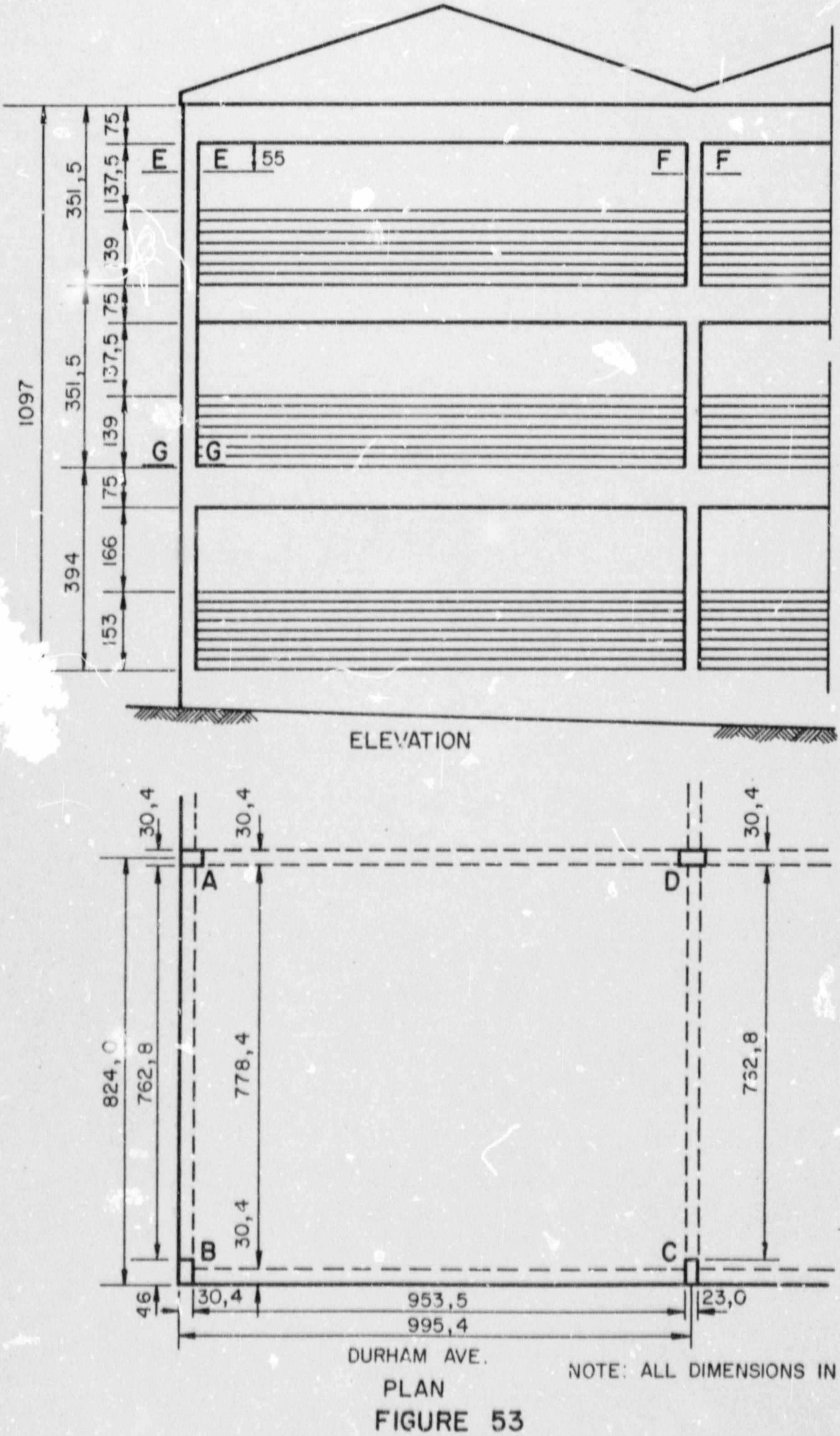

FIGURE 53

Dimensions of building

starts at the bottom corner of the brick wall and curves downwards until it is again a vertical crack at about the level of the bottom of the beam or sometimes well above this level. This vertical crack tends to be very close to the external corner of the column, i.e. 15 to 20 mm from the corner. No cracks of any significance could be observed in the brickwork except a horizontal crack below the top course under the windows.

At the corner columns at both the first and second floors, two beams at 90 ° to each other and carrying brick walls join the columns. The cracks described above occur in both outside faces of the columns. As cracks were not observed on the faces of the columns in contact with the windows, the two crack systems must have joined internally. If horizontal sections at different heights were to be taken through the concrete of the junction, the internal crack is likely to be revealed as a wide-'V' shape, with the bottom of the 'V' towards the inside of the building and rounded a fair amount; the top of each arm of the 'V' ending at the column surface. No estimate of total crack widths could be made as there were signs that the cracks had been repaired at least once.

There is no ground-floor beam under the ground-floor brick spandrel panel and a vertical crack is in evidence from the bottom corner of the brick wall going downwards parallel to the column. This crack reduces in width as it goes downwards, tailing away at ground level. There is also a vertical crack from the bottom corner of the brick wall going upwards for about 1 m. In the vicinity of the top of the brick wall, there are a number of horizontal cracks starting at the outside corner of the reinforced concrete column and reducing in width towards the middle of the column. See Figure 50. The longer of these cracks ended about 220 mm from the corner across the 304 mm width of the column facing Durham Avenue and about 330 mm from the corner across the 460 mm width of the column facing the other street.

Similar / ....

Similar cracks could be seen in column B in the vicinity of the top of the brick walls at the second and third storeys.

The top course of brickwork just under the window cill has a horizontal crack between it and the rest of the wall. This horizontal crack is about 6 mm open in the centre of the wall and tails away at the ends.

6.2 Determination of Reinforcement in Beam and Column

Information on the actual reinforcement in the building could not be obtained, so that the probable reinforcement in beam BC and column B has been computed in accordance with the permissible stresses and formulae in use at the time when the building was built, about 1948 to 1950.

The service loads for which the building would have been designed would have been higher than the 2 kN/m² actually observed in the building. The superimposed load for light industrial use, that would have been used at the time this building was designed and built, would have been 100 lb/ft² (4,79 kN/m²), so that this superimposed load was used in the calculation of the reinforcement.

It was necessary to estimate the reinforcement with reasonable accuracy so that the elastic constants of the concrete could be modified, by allowing for the steel, before use in the finite element analysis. The calculations associated with designing the steel reinforcement are given in Appendix E. The estimated reinforcement is shown in Figure 80 in Appendix E and in Figure 54.

6.3 Method of Theoretical Analysis

The method of analysis most suited to theoretically analysing the magnitudes and directions of the principal stresses at