NOTES ON CRACKS IN BUILDINGS IN DERA GHAZI KHAN.

By J. H. Johnston, B. Sc. (Edin.), Assoc. M. Inst. C. E.

In 1910 the long struggle between the Indus and the Engineer for the possession of old Dera Ghazi Khan ended in the complete victory of the river. The city was swept away by its waters and the inhabitants retreated inland and started to build a new city at a safer distance. New Dera Ghazi Khan is about 12 miles from the river on a strip of flat alluvial plain about 30 miles wide which lies between the Indus on the east and the foothills of the Sulaiman range on the west. The soil consists of irregular beds of clay, and of all grades of sand and gravel, and must have been deposited by the hill torrents. This action is in fact still going on. The streams on entering the plains break up into several channels and wander over the country depositing their burdens on the way.

Dera Ghazi Khan is laid out in two parts; the city to the north and the civil station to the south. A new and large canal has been made to pass close to it and as a result the original desert has largely been replaced by cultivation.

About two years ago when the building of the civil station was nearing completion a new difficulty appeared. Several buildings which had just been finished began to develop dangerous cracks. These cracks were not confined to the masonry but were found to extend along the ground for several feet. They have up till now continued to open out and one building in consequence has had to be dismantled. This is the Police Hospital. The N.-W. corner showed a settlement of 3", there was one main crack running N.-E. and S.-W. right through it and another at right angles to it. These cracks could be traced in the ground for about 15' from the building on both sides and appeared to extend into the soil to a depth of approximately 10'. The larger crack measured 1½" at plinth level and 2½" at the top of the roof. It followed the line of least resistance through the arches and doorways. Levels were taken at the top of the verandah parapets and these were found to slope down from the cracks towards the N.-W. corner. The photographs show the larger of the two cracks (the ladder is on the north side of the hospital).

These cracks are typical of, though larger than others which have appeared in other buildings. They all follow the lines of least resistance, arches and doorways. They are generally wider or more prominent at roof level than at plinth level but appear to show no preference for any particular locality except that buildings in the same compound are liable to attack. Five other houses a few feet away from the hospital

are damaged. The Dak Bungalow and the residence of the Superintendent of Police are affected yet the P. W. D. Rest House a hundred yards away has escaped. Some damage was done by a flood in 1917 and it is said the Police lines suffered most. Since then a protection bund has been made and there have been no serious floods. Telltales show that the cracks continue to develop but observations have not been made over a long enough period to say whether the movement is more at one time than at another.

Several attempts have been made to explain the cause of this trouble. The popular theory is that the soil being of clay contracts on drying and in consequence large cracks are formed which, if they happen to pass through a building rend it asunder. Endeavour will be made to show however that this theory fails to explain the observed facts. In a paper on "Some Notes on Cracks in Buildings in Balasore" printed by the Government of Behar and Orissa the contraction theory was put forward to explain the case. It was there stated that the cracks in the soil opened and closed during the year as the seasons changed. The buildings were founded on black cotton soil. No mention is made of settlement having been observed.

The present writer would tender his own explanation. In doing so he does not suggest that he has said the last word on the subject. The theory is based on the fact that settlement has been observed. It can only be proved true or otherwise by a much fuller investigation. He hopes however that it will be useful as a working theory for such investigation. The cracks are in his opinion due to settlement caused by the shifting of the underground sand through the action of water. The soil during floods may be compared to a filter bed working under an excessive head. A crack may be formed in the following ways :—

(*a*) by settlement,

(*b*) by upheaval,

(*c*) by horizontal movement due to contraction or other geological cause.

Of these the second will not be considered and endeavour will be made to show that the third is an unsatisfactory explanation of the problem.

The sections of two borings made in connection with the city water supply illustrate two main facts. First that the soil is porous and second that the beds vary considerably and become coarser as the depth increases. This is what we should expect from the nature of the rivers from which they were deposited. That the soil is porous may be seen in other ways. As the level of the Indus rises the water table of the surrounding country rises with it and all depressions are flooded. It is said that the irrigation engineers had difficulty in preventing leakage in the new Mankha canal. The water would escape and re-appear in borrow pits some distance from the canal banks. The diagrams show that the spring level of the water was at that time between 23′ and 26′ below the surface.

From experiments on wells we know that a velocity of more than four feet an hour through sand will disturb it and cause the well to "blow." Is there any likelihood of this velocity being attained in the sand and gravel beds below Dera Ghazi Khan? From Mr. Farrant's paper on the Yield of Wells* it appears that a gradient of 1 in 4 will give this velocity. Referring to experiments at Ambala he gives the equation of the cone of depletion round a well as :

$$h = He^{-0{\cdot}05\,x}$$

where " h " is the depth below normal spring level at a distance " x " from the well and " H " is the head under which the well is working. Differentiating we get :

$$\frac{dh}{dx} = -0{\cdot}05\,He^{-0{\cdot}05\,x}$$

If $H=5'$ and $x=0$

$$\frac{dh}{dx} = -0{\cdot}05 \times 5 = -\frac{1}{4}$$

Now 5′ is the head over which a well may blow and the above equation shows that the gradient in the immediate vicinity of the well is then 1 in 4.

If water enters a soil of uniform composition it will spread out in the form of a bell-mouthed cone which will appear to stand on the surface of the water table. The gradient of the sides of the cone will decrease as the depth increases. It will in fact be the case of the " cone of depletion " of a well turned upside down. If however the soil becomes more porous as we go deeper, as illustrated in a filter bed the sides of the cone may become steeper instead of flatter. This means increased velocity. If a bed of fine sand lie on top of one of coarse sand water coming from the surface will increase in velocity as it passes from the one bed to the other and if the gradient of the cone at this point be steeper than 1 in 4 the fine sand will be carried away. This action would take place if large volumes of water from the surface found access through a crack in the clay. Now this is exactly what happens to the hill torrents west of Dera Ghazi Khan. When in flood they wander over the country until they find an opening and disappear underground. Such a flood is said to have reached the station in 1917 and in the author's opinion it is this flood which is responsible for the damage to the Police buildings.

The same action might be expected if the surface between the beds of fine and coarse sand referred to above were inclined to the horizontal and passed through the water table. If the underground water was moving from the side of the fine sand we should expect a drop in head as it passed through into the coarse sand.

* Notes on the Yield of Wells by J. T. Farrant, Punjab P. W. D. Paper No. 63, Simla 1909.

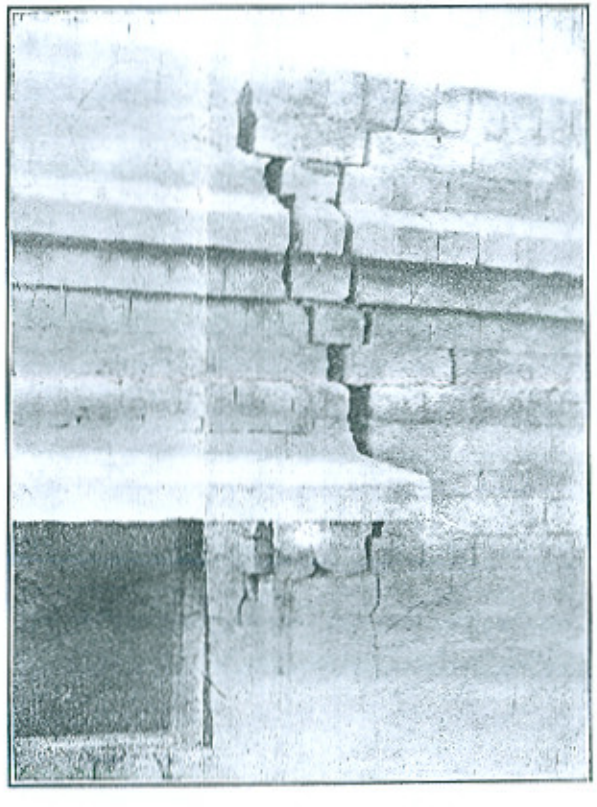
The theory has been put forward that the cracks are due to contraction of the clay. The only cause of this would be reduction of volume on drying. This is a common phenomenon and may be seen in the bed of any river in the plains. The photograph shows such cracks in the bed of the Indus. They are about two feet apart in two directions at right angles to each other. The clay also gives way by shearing along horizontal planes. The factors which determine the distance between cracks could only be discovered after a full investigation but we should expect this distance to vary with the depth below the surface of the plane of "no contraction" or with the relative dryness of the under layers of clay. It appears also that as the clay dries the cracks rapidly increase in number until a minimum spacing is reached after which any further contraction causes it to shear along horizontal planes and curl up in thin laminae.

If this is correct we should expect the full number of cracks long before any one has widened 1½". We should expect to find them every two or three feet apart. But there is no such system round the Police Hospital at Dera Ghazi Khan. Nor does the theory explain the settlement of three inches nor the increase in width of crack at roof level.

Of suggestions of how best to meet this difficulty the writer has few to offer. To allow for a settlement of 3" in 20' nothing less than a reinforced concrete raft designed as a cantilever to carry part of the building would seem necessary. The station is now protected from floods by a bund. Cultivation by protecting the surface from local floods and filling up existing cracks would probably help. The P. W. D. Rest House which is not affected is surrounded by cultivation. Two-storey buildings of small plinth area might be expected to have more resistance against unequal settlement.



North end of Police Hospital.



Crack north end of Police Hospital.



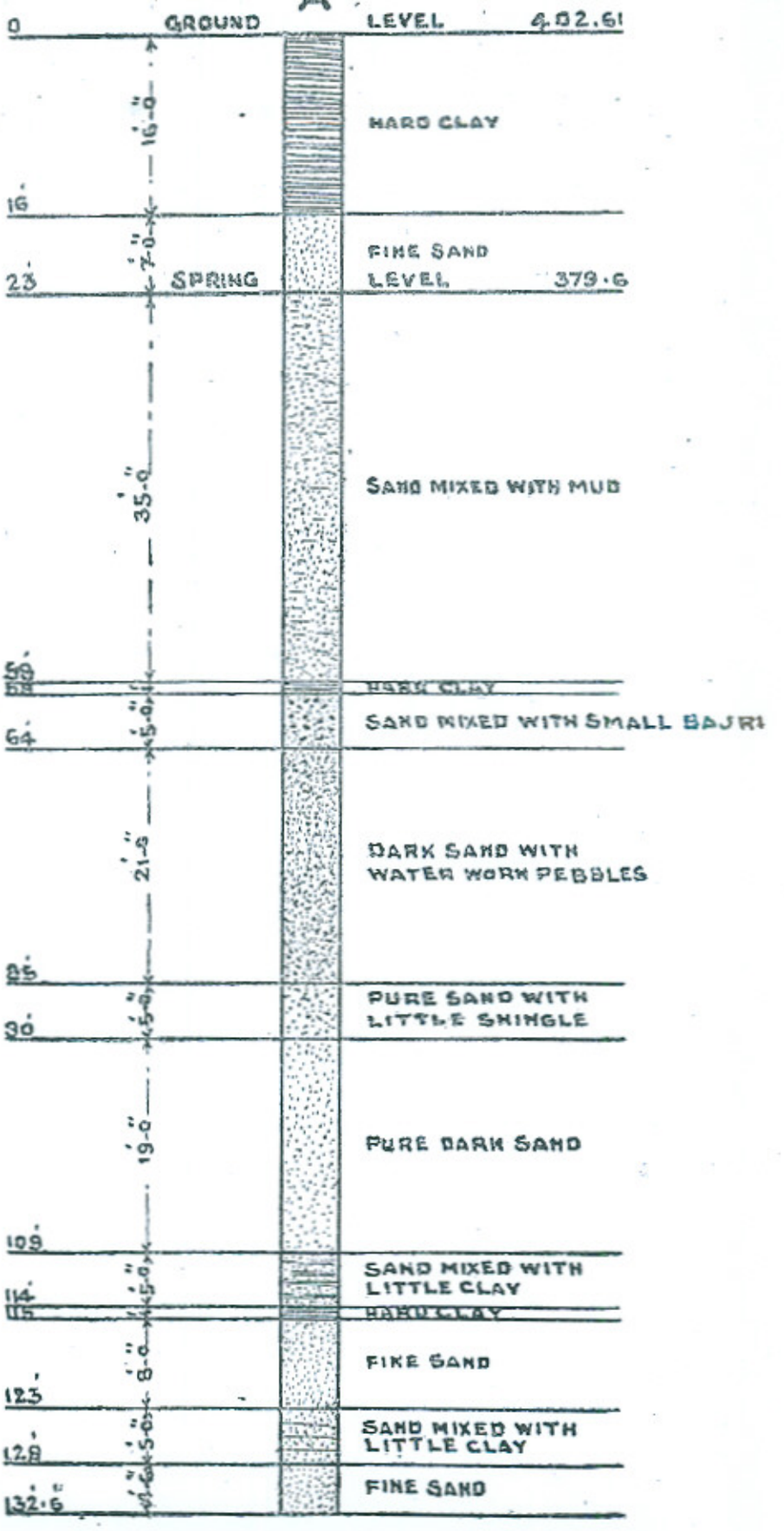
Contraction Cracks in clay on drying.

NOTES ON CRACKS IN BUILDINGS IN DERA GHAZI KHAN

SECTION OF BORING

SCALE 1" = 20'

A

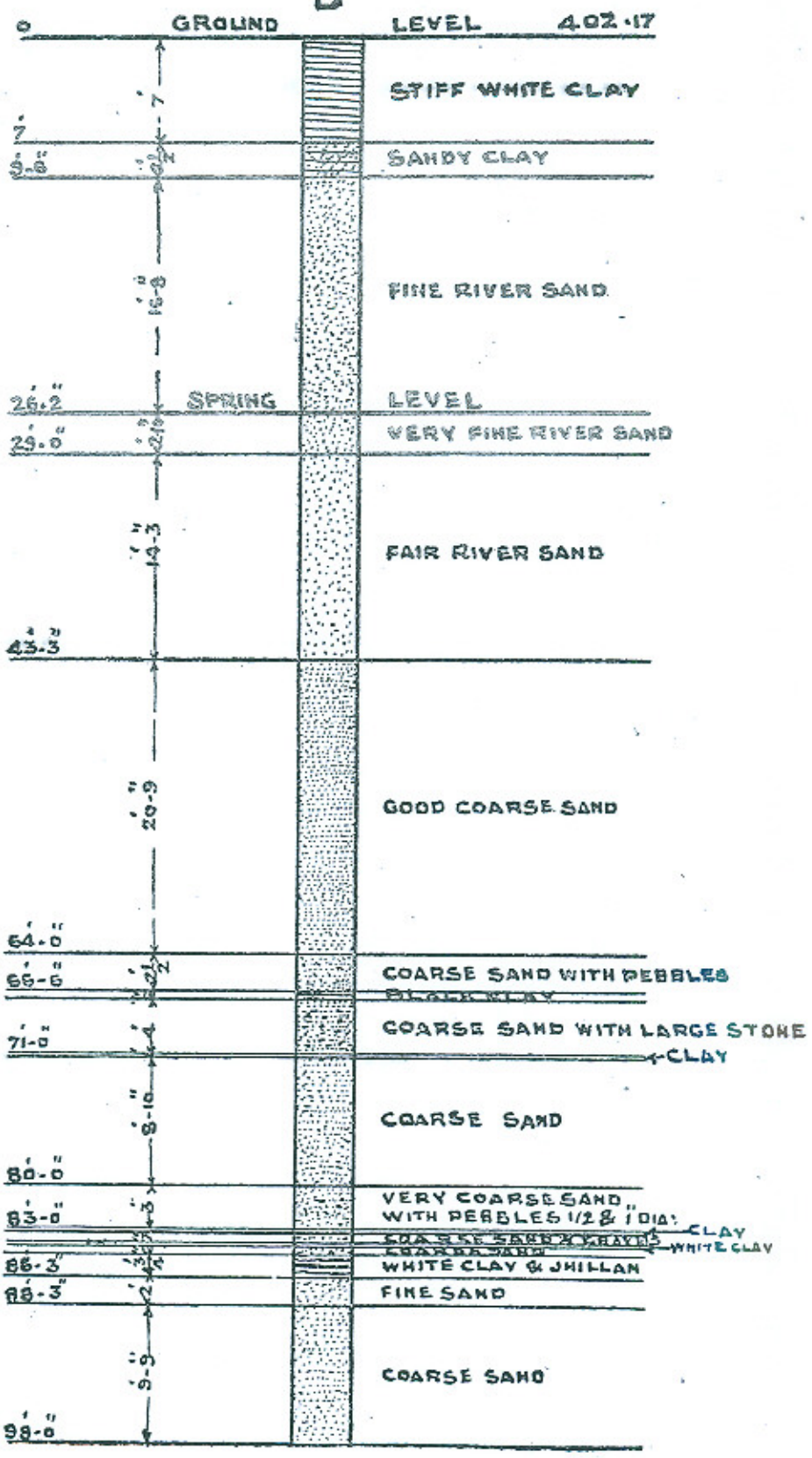


NOTES ON CRACKS IN BUILDINGS IN DERA GHAZI KHAN

SECTION OF BORING

SCALE 1" = 16'

B



DISCUSSION.

MR. JOHNSTON in introducing his paper regretted that Mr. Wilsdon was not present to give his opinion. He however hoped that the Irrigation Engineers present would be able to help in solving the problem. In his opinion the contraction theory was untenable. It would presuppose not only an opening but also a closing up of the cracks as conditions charged but in this case the cracks did not close up.

MR. B. P. VARMA agreed with the author that the 1917 Flood was probably the cause of the damage to the Buildings at Dera Ghazi Khan. Settlement could be the only reason for such cracks. He referred to Mr. Iqbal Hussain's paper read before the Congress in 1920 in which certain experiments were described shewing that certain classes of soils contracted when water was added. He considered that it was possible that the 1917 flood saturated the ground causing contraction, which in turn caused the cracks noted.

MR. E. D. COCKBURN did not agree with the author that the section shewed porous soil, as layers of 7 and 16 feet of clay could not be classed as such. The statement also, that the soil on which Dera Ghazi Khan was built had been deposited by the torrents from the Suleiman Range, appeared to be incorrect as it was generally agreed that the deposit was due to the Indus. Dera Ghazi Khan was essentially a dry tract but it was sometimes subject to very heavy falls of rain, that is to say there were long periods of dry weather followed by short periods of heavy rainfall, and in 1917 there was very heavy rain. His theory was that the flood water entered through cracks but that the cracks must be there first. These, in the speakers opinion, were due to contraction of the clay caused by heavy rainfall followed by a long dry period. He was unable to explain why the P. W. D. Rest House and various other buildings remained unaffected while those referred to in the paper failed.

MR. ARMSTRONG said that the Police Hospital at Dera Ghazi Khan was so badly cracked that it had to be dismantled down to the top of the concrete foundations. He personally took careful levels on this concrete and found no appreciable settlement, but cracks existed below those in the superstructure, and in some cases the horizontal displacement of the concrete amounted to one inch, showing that the movement had been horizontal and not vertical. This was borne out by a trial pit 12 ft. deep dug on the line of a crack in the Municipal Hospital. In this case the crack in the soil was over an inch wide at ground level and about half an inch at 12 ft. depth. Here also though cracked on the line of the fissure in the earth the building showed no appreciable vertical settlement.

The system now being adopted at Mr. Cockburn's suggestion was to isolate the foundations of new buildings by sand trenches all around them. Still more recently this idea had been modified by digging the

excavations for founds wider and deeper than the masonry, and filling below and around with sand. The concrete had been made of reinforced cement and the filling underneath floors was of sand.

MR. A. ST. G. LYSTER referred to a very similar case that had occurred at Ambala in the Civil Station. In about 7 or 8 compounds cracks occurred, some buildings being affected and others not. The affected areas were traced and followed a distinct but irregular line which crossed the road, under which it was feared there might be a cavity into which a heavy steam roller might drop. It was found that the line of weakness ran out into an old torrent bed. A 30 foot bore hole was put down and the section shewed clay with very fine sand, and a layer of clean sand about 4 feet below the surface. The speaker was transferred from Ambala before it was decided what the remedy should be, but he understood that a trench had been excavated around each house affected and afterwards filled with good clay thus insulating the buildings from any movement of under ground water. Before leaving he had looked up the history of the Civil Station for the period it was being built, and it was interesting to note that similar trouble had occurred then, which was many years ago.

MR. H. W. NICHOLSON said that trouble had occurred on the Upper Jhelum Canal. Several buildings had settled very seriously and this he ascribed to the saturation of the soil to an extent not possible before the opening of the canal. At Sulcimanke he was excavating the trenches for his buildings wider and deeper than was necessary for the concrete, and filling with clean sand to spread the pressures.

R. S. L. SANT RAM remarked that he followed Mr. Lyster at Ambala and so it fell to him to deal with the trouble described. He found that there was a thin layer of clean sand 5 feet below the natural surface, sandwiched in between two layers of clay. This layer of sand outcropped in the beds of nalas in the vicinity and storm water percolated into it in the rainy season. As the water in the nalas subsided the wet sand flowed back into them, causing cavities to form above, which in turn caused settlement. The remedy was to excavate trenches round buildings, where necessary deep enough to cut off this stratum, and to fill them with clay so as to prevent the movement of water and sand in the soil under the buildings. He did not agree with the author's theory of settlement. He had built the police office which had cracked, the soil there being stiff clay for a considerable depth below ground and very little sand. He had had experience of the subsoil at Dera Ghazi Khan, Jullundur, and Hoshiarpur, and from borings he found very little difference and yet in the last two districts named, cracks do not appear. In fact the borings he had examined shewed nothing that would account for cracks in one place and not in another. In Dera Ghazi Khan, he considered that the abnormal rainfall that sometimes occurred, followed by long periods of hot dry weather, produced the cracks, the stiff clayey soil suddenly drying, as in the clayey bed of a river or torrent.

MR. K. G. MITCHELL did not follow Mr. Varma's suggestion that the settlement of the surface stratum of clay could be attributed to the shrinkage of the sand below under the influence of water. That such shrinkage did take place in certain circumstances could not be disputed; but was it claimed that sand once shrunk in this manner would expand again, if allowed to drain or dry off gradually, and under the pressure of the clay above? Surely not, such shrinkage would take place once and once only. Carried to its conclusion therefore Mr. Varma's theory was that the sand strata in question had never been wet before, or that the Almighty had waited for centuries till new Dera Ghazi Khan had been built and had then let water into the cellars.

The phenomena described in the paper indicated a change in conditions, and it appeared to him to be natural to connect such a change with known alterations in the geography of the country. Speaking roughly Dera Ghazi Khan was now he believed, about ten miles from the right bank of the nearest cold weather channel; twenty years ago this distance was probably fifteen miles. The effect of this would be that the slope from a point in or under Dera Ghazi, fifteen feet above low water level, was previously 1 in 5,000 and was now 1 in 3,300. It had been suggested in the discussion that much of this underlying sand became at times practically a quicksand, and if this were the case, the steepening of the slope which he suggested, might be the cause of periodic slips in this quicksand which would thus from time to time leave the band of clay above without support, and could account for the phenomena experienced. That this effect could penetrate inland for ten miles might appear to be absurd, but he remembered in connection with some dredging off Southampton docks in the muddy bottom of the estuary, that when the cut was only a few feet deep and twenty feet wide, a low spring tide revealed the fact that the mud was slipping and walking into this cut, the effect being visible for considerable distances away. A quicksand would be more susceptible than mud, and, as he thought, though the causes might operate gradually, the effect would be periodic slips and settlement at considerable intervals.

MR. DORMAN stated that he had prepared a note on what had happened at Ambala, which unfortunately could not be printed in time to appear in the preliminary issue of the papers, but which he understood would be included in the final issue of the Proceedings. He was sorry Mr. Johnston had not given particulars of what had happened at Balasore in Orissa where the conditions appeared very similar to Dera Ghazi Khan. Building on trenches filled with sand, which had proved successful in Bengal, proved an entire failure at Balasore, probably due to the size of the cracks through the trenches being still sufficient to let the sand escape, although the trenches were six feet deep. Providing sand trenches round a building in an attempt to isolate the foundations was equally unsuccessful.

The large double-storied hospital, with broad columned verandahs, stood intact beside a single-storied ward riddled with cracks. The reason was that part of the site of the main building lay on an old tank, and consequently the whole of the foundation had been constructed on timber piles which went down below the influence of the seasonal expansion and contraction of the soil.

Another method which had proved satisfactory consisted in providing reinforced concrete foundations over one or two courses of brick laid dry in the bottom of the foundation trench.

MR. C. D. M. HINDLEY mentioned that his old Railway, the East Indian, passed through country containing a great deal of black cotton soil which was proverbially treacherous. It cracked in a similar way to that described by the author and it was considered that these cracks were caused by expansion and contraction due to seasonal fluctuations of moisture content. The general practice in building on this soil had been to excavate 6 foot trenches 6 or 8 feet deep. These were filled with ashes from the Loco yard and the foundations then laid in the usual way. This had proved successful and had saved buildings from cracking. He recommended rammed ash as a suitable material for use in cases similar to those under discussion.

MR. JOHNSTON in reply thanked the speakers for their criticism. He thought they had brought to light quite a lot of evidence to show that movement of underlying sand had been the cause of settlement and cracks elsewhere. Many speakers seemed to ignore the fact that settlement had been detected or else they doubted the author's ability to take levels. The settlement had been measured with a good dumpy level placed on the roof of the building with only one "setting up." He regretted he had not read Mr. Iqbal Hussain's paper. Mr. Cockburn had done his best to pull to bits all the author's theories but had not attempted to defend the contraction theory or advance any of his own. A layer of clay 7 to 16 feet thick might quite easily settle and crack if supported from below only by a uniform hydraulic pressure. Mr. Cockburn was probably right in saying that most of the beds were laid down by the Indus, yet beds of gravel were seldom carried far from the rocks from which they had their origin. The theory advanced was that movement was caused either by flood water entering from above or by the seasonal rise and fall of the Indus. The difficulty in accounting for the first cracks disappeared when we considered the influence of the Indus. The cracks were due to unequal settlement or to unbalanced upward pressure from below. Buildings round the edge of a cavity or where this inequality was greatest would therefore be most liable to damage. The P. W. D. Rest House had probably escaped by settling uniformly. The author could not account for the fact that there had been a drop of 3 inches at one corner of the top of the verandah parapet, yet Mr. Armstrong had found no corresponding difference in level in the foundations.

The drop could quite easily be seen by looking along the parapet and there was a uniform slope from the crack to the corner. Mr. Armstrong did not attempt to explain the increase in width of the crack from the foundations upwards. It seemed unnecessary to show how a vertical displacement could give rise to a horizontal one. Several speakers had referred to Ambala and Mr. Sant Ram gave a similar explanation of the cracks there. If his remedy of building puddle walls round the trecherous sand were carried out at Dera Ghazi Khan he would have to excavate 20 to 30 feet deep. The author knew neither Jullundur nor Hoshiarpur, but wondered whether there was anything there to compare with the large rise and fall of the Indus. He did not think the remedy adopted by Mr. Nicholson at Suleimanke would be of any use at Dera Ghazi Khan.

Mr. Mitchell's theory was very interesting and useful. The author had found that only a very steep gradient in the water table would produce a velocity sufficient to disturb individual grains of sand, but if, as Mr. Mitchell suggested, the whole of a bed of fine sand moved as one liquid mass the necessity for assuming a steep gradient disappeared at once. The overlying bed of clay might be pictured as floating on this quicksand. It would tend to rise and fall in proportion to its weight or thickness. The author did not think the conditions at Balasore could be compared with those at Dera Ghazi Khan. The soil there was black cotton of which he had had no experience. The remedy referred to by Mr. Hindley had the effect of reducing the pressure per square foot by the use of an incompressible material, but the clay at Dera Ghazi Khan was in this respect an excellent foundation. It had the property of spreading the load carried over a large area.