SURFACE SUBSIDENCE AND STRUCTURAL DAMAGES DUE TO UNDERGROUND LONGWALL COAL MINING - A CASE STUDY

by

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ABSTRACT

The surface subsidence of the longwall section of an Eastern Ohio Mine was monitored. The program involved a network of 250 monuments (1) in the panels distributed in 3 cross-sections, (2) on the county road passing through one end of the panels, (3) on an active 30-in diameter gasline and (4) on two angle towers for power transmission lines. The angle of draw was approximately 33 degrees, subsidence factor ranged from 0.595 to 0.7. The subsidence profiles, subsidence profile and subsidence development curves were presented and discussed for all the structural elements monitored. The study indicated that depending on the locations of the surface structures, the surface structural damage can be minimumized and that most structural damages can be made to be temporary.

INTRODUCTION

One of the biggest concerns in introducing modern longwall mining method into U.S. Coalfields was that it would cause considerable enviromental damage as a result of the large scale surface subsidence. Because longwall mining creates much larger openings than those by room-and-pillar mining. The problems of surface subsidence and its associated structural and enviromental damages have therefore received considerable attention by the coal industry. In addition, the Surface Mining Reclamation and Control Act of 1977 mandates that surface subsidence control plan be an intergral part of the underground coal mine design. Accordingly, many major coal companies that operate coal mines, with or without surface right, near population center, and/or under areas with active surface structures are likely to have some type of surface subsidence monitoring program or programs (1).

This paper describes the surface subsidence monitoring plans sponsored separately by three different companies, i.e. (a) the coal mining company that performed underground longwall mining, (b) the power company that operated the high voltage transmission power lines across the mine property, and (c) the utility company that operated a gas pip across the mine property.

The objectives of the subsidence monitorin were (1) to obtain operating data concerning th characteristics of surface subsidence and its e on surface structures, and (2) to monitor conti the surface structural response such that immedi preventive measures could be taken to eliminate reduce damages.

MINE SITE AND MINE PLANS

The mine is located in Eastern Ohio near t river. The Pittsburgh coal seam is flat within mine property and is approximately 5 ft. 6 in. with an overburden ranging from 350 to 800 ft. surface terrane varies considerably over the mi property. Most of the area are heavily vegetate The borehole log in Fig. 1 shows the typical st graphic sequences over the Pittsburgh seam. Th immediate roof is weak shale which caves in the as soon as the powered supports are advanced.

The subsidence monitor was conducted in the longwall section which consisted of three lon panels. The panel widths ranged from 465 to 50 and lengths from 2200 to 3200 ft. Panel develo consisted of three entries, each 20 ft. wide. rectangular chain pillars near the headentry we ft. wide whereas those on the tailentry side we ft. wide. Pillar length between cross-cuts was uniform at 70 ft. but the cross-cuts among the rows of chain pillars were staggered to increas stability. The area to the north of panel No. previously been mined out by room and pillar me

The coal at the face was cut by the shear roof was supported by the 500-ton two-leg Lemin shields manufactured by Hemscheidt of America. average rate of face advance was 20 ft.

SUBSIDENCE MONITOR PLANS

Fig. 2 shows the overall subsidence monito The following legend will be used throughout th paper: the dotted lines are surface topographic

r lines and subsidence monuments are denoted by
dots, each of which is designated by a letter
ed by a numerical number. However, those
nts along the gasline are represented by the
ional survey practice of numerical distance.
-series monuments are steel spike, 6 inches long,
all the way down at the center of the paved
road. They numbered 62 and were spaced at 30
he county road runs approximately in North-South
ion near the bleeder (east) ends of the panels.
-series monuments are wood spikes, 1-in. square
ss-section, 2 ft. long, the bottom 18 inch was
into the ground leaving 6-in exposed above the
surface. They numbered 104 and distributed in
jor cross-sections: one along the center line
el No. 1 and the other on the valley which cut
h the whole longwall section. Another monument
section was located along the gasline but the
nts were located within the first panel. All
se monuments were spaced at 30-50 ft. center-
ter.

here were three gaslines operated in the pro-
before longwall mining was initiated. The
aslines were steel pipes with 18-in., 21-in.,
-in., in diameter, respectively. When the
ll mining started, the owners of the two
gaslines decided to reroute the pipelines
the mine property with new lines. Subse-
, the smaller two gaslines were abandoned and
attended. The owner of the 30-in. pipeline
to monitor the subsiding characteristics of
eline and take whatever preventive measures
rily to keep it in good operating conditions
out the mining period. The subsidence monu-
ere simply the top surface of the pipeline
ced at 50 ft. center-to-center.

ere were two angle towers in the longwall
. Tower 110 located approximately 85 ft. from
thern rib of panel No. 1 and Tower 111 also
approximately 95 ft. from the northern rib of
o. 2. The two towers were 1000 ft. apart.
le towers were designed to carry 138 KV high-
power lines (Fig. 3). The concrete floor on
face was 1 ft. thick. The 10 ft. deep footing
ed no extra reinforcement. The subsidence
plans included the amount of subsidence at
rner point, i.e. LF (left front), LR (left
RF (right front), RR (right rear) where
ectional symbols were defined when facing
he power lines southeast. The horizontal
distances between neighboring footings at the filed notch were also monitored. So were the distances between the diagonally opposite footings.

Most subsidence monuments were concentrated in the first panel. The plan was that sufficient and reliable data on the subsidence characteristics of the region can be established and that they can be used to predict and subsequently to take preventive measures for reducing and/or eliminating surface structural damages in the following two panels and offer longwall sections in the area. Therefore, the monuments were surveyed meticulously and frequently throughout the mining period of the first longwall panel.

All of the surveys were performed with transits with each reading accurate to 0.01 ft. All of the measurements were vertical subsidence and no horizontal displacement was determined.

SUBSIDENCE DATA AND DISCUSSIONS

Fig. 4 shows the subsidence contour lines at three different face locations when the first panel was mined. In Fig. 4A, the face was about to pass the valley leaving behind a gob whose surface slope ranged from 6 to 23%. Regardless of the topography, the subsidence contour lines were essentially symmetrical about the center line of the longwall panel. This suggested that surface topography has little, if any, effect on the final subsidence contour as found elsewhere (1). However, the zero contour line to the north spreaded farther as compared to that in the South side. Similar trends were found in Figs. 4B and 4C. This was attributed to the facts that the northern area has been mined out by room and pillar method previously and that the chain pillars between the mined out area and the first panel are deteriorating. This phenomena were found elsewhere in the Appalachian Coal Field (2). The final subsidence contours in the first and second panels when the face was at the third panel is shown in Fig. 5. The subsidence contours remained symmetrical about the center line.

Specifically the data presented in Figs. 4 and 5 can be reorganized to address the following controlling factors: subsidence profiles, angle of draw, subsidence factor, and subsidence development characteristics.

A. Subsidence Profile

Subsidence profiles were drawn mannually to fit the measured subsidence. Extreme care was exercised in defining the point of zero subsidence which always involved some measure of extrapolation. Fortunately almost all the monuments beyond the edges of the first panel were spaced at 30 ft. or smaller which reduced the error of extrapolation. Considering the seam depth and the monument spacing in this case study, it was estimated that the maximum error of the angle of draw determined was 1.5 degrees.

Fig. 6 shows the final subsidence profile at the valley. Based on the depth and width of the panel, and the angles of draw measured, it was a critical width of opening. The final subsidence profile along the county road (Fig. 7) showed much smaller mangitude and area of influence than that found in the valley. Because the county road was located near the bleeder end of the panel. Consequently no noticeable damage was imposed on the road after mining. The points where maximum slope occurred were located within the longwall panels in both profiles. The maximum slope for the valley was 2.1%. It was 1.13% for the county road. Both of which were rather low.

Fig. 8 shows the progress of the development of the subsidence profile along the valley. When the face was 200 ft. inby, the surface experienced a heave (a curve). The heave quickly disappeared at the center of the panel and surface started to subside as the face approached the valley. But the heave did not disappear on the left side beyond the edge of the panel until after the face had passed the valley more than 300 ft. (C curve).

B. Angle of Draw

The angle of draw defines the limit of surface subsidence beyond the edges of the longwall panel. It was found that the angle of draw was 32-33 degree along the valley. This angle of draw was used in determining how close the third panel could be mined toward the west where a major interstate highway passed by. This was the reason why the length of the third panel was 2200 ft.

C. Subsidence Factor

Subsidence factor is the ratio of the maximum subsidence at the center of the subsidence profile to the mining height. It is a measure of maximum possible subsidence. The subsidence factor was 0.595 in the valley where the overburden was 380 ft. thick. It increases to 0.7 along the gasline where the overburden was 750 ft. thick. It seems to be contrary to the general belief in that subsidence factor increases with seam depth. Similar trend was found elsewhere in the Appalachian Coalfield (3). A plausible explanation has been offered for this phenomenon: Longwall mining induces caving at the immediate and intermediate roof strata. The caving process propagates upward to a horizon located at a distance of approximately 35 to 50 times the mining height over the coal seam. The deformation above this horizon observed by Dahl and Von Schonfeldt (4) is continuous, i.e. no appreciable breakage but some bed separation may occur. The main roof strata settles down in more or less a continuous piece on the gob without any appreciable increase in volume. As it settles, the main roof strata will compress the underlying immediate roof which had caved and broken to fill up the gob. The thicker is the overburden, the thicker will be the main roof. A thicker main roof will compress more the broken immediate roof than a thinner one (3).

D. Subsidence Development Curve

Fig. 9 is the composite subsidence development curve. Surface subsidence at any surface point. P started when the face was 550 ft. inby. The subsidence increased rapidly. The subsidence slowed down again when the face had passed the point P more than 400 ft. Subsidence was complete when the face was more than 800 ft. beyond the point P. Notice the horizontal axis is the actual practice of using a dimensionless term, i.e. ratio of face distance to seam depth. The curve also shows that though surface subsidence was induced far ahead of the face, the majority of the total subsidence occurred after the face had passed; that the zone (or distance) of influence before and after the face had passed was different with the latter always be larger; and that no measureable amount of subsidence coule be attributed to "time effect".

E. The Gasline

The 30-in. gas pipeline was survey very frequently. The pipeline had a sectional length of 40 ft. It was welded at the joints. It was determined that the pipeline can not withstand a maximum differential subsidence of 0.2 inches between monuments. In order to keep the pipeline in the original elevation, a wood crib was built under each monument to support the pipeline. If a monunent was found to have subsided 0.2 inches or more in each subsidence survey, the crib immediately underneath the monument was raised to its original elvation by wedging. The pipeline intained this way throughout the period of

sed on the accumulated subsidence measured for
nument on the pipeline, a subsidence profile
Fig. 10 was obtained. Comparison between
and 10, it was found that the angle of draw
ller for the pipeline; that the subside profile
ter; and that subsidence factor is larger. The
subsidence profile and the smaller angle of
re attributed to the steel pipeline that
subsidence better than the rock beam (strata).
ar the edge but on the surface of the longwall
the 21-in. and 18-in. pipelines were found to
scrupted at the joints without any damage to
elines. Obviously the joints are the weakest

The Angle Towers

e measured subsidence at the footings and
between the diagonally located filed notches
wn in Figs. 11 and 12 for Tower 110 and 111,
ively. The footings of Tower 110 started to
when the face was 1000 ft inby (Fig. 11).
e face was directly underneath the tower, the
s had subsided from 6.6 to 8.6% of the total
possible subsidence. The footings and ground
subsided rapidly until the panel was finished
outby. The advance of the face in panel No.
ased slightly the subsidence of the footings.
essentially similar to the subsidence develop-
rve described in Fig. 9.
nce the filed notches were only 1.5 ft. above
face, the strains measured at that level were
to be similar to those occurred on the sur-
When the face was 1000 ft. inby, tensile
on the ground started on both directions,
1) i.e. RF-LR which was approximately parallel
face while RR-LF perpendicular to the face.
face approached the tower, they increased
. When the face was directly underneath the
tensile strain in RF-LR jumped up whereas that
R-LF reversed to become compressive. As the
ved along, both the tensile strain along RF-LR
pressive strain along RR-LF decreased. This
in conformity with most subsidence engineers'
that the instantaneous traveling strain is
than the final strain that exists.
Fig. 12 the subsidence development curves are
ally similar to those shown in Fig. 11. But
ain curves are quite different. Tensile
strain parallel to the face direction was induced when the first panel was being mined while the strain perpendicular to the face direction oscillated from tensile to compressive and vice versa. When the second panel strated, the strains in both directions were tensile and remained so throughout the mining period of the second panel.

Based on the maximum differential subsidence of the footings, both towers tilted toward the center of the panel along the direction of RF-LR which was parallel to the face line. The angles of tilt were 1° 23' for Tower 110 and 1° 40' for Tower 111, respectively. The tilts produced a horizontal displacement along the direction of power lines of 2.12 ft. and 2.55 ft. for Tower 110 and 111, respectively. The direction of horizontal movement was such that it reduced the line tension and increased the line sag. The law requires that a minimum clearance of 28 ft. shall be maintained between the lowest line and fixed objects. This had never been violated during the course of mining. Furthermore, the tilt angles were too small to cause any stability problem for both towers. The amounts of detorination in both towers were so close that the data obtained from the first tower were used to predict accurately what was going to happen to the second tower before panel No. 2 was started.

CONCLUSIONS

Surface subsidence and its associated structural damages due to underground longwall mining can be minimuzed by proper underground panel layouts. For instance, the County Road which was subparallel to the faceline in the first panel experienced considerable amount of subsidence but no visible damage was shown on the pavement. The same county road on the third panel where it was perpendicular to the faceline showed tensile fractures and required pavement repairs.

The gasline adjusted as required, was not subjected to any form of damage and remains in service. The angle towers tilted slightly which did not exert any unuaual force to the towers, and consequently no adjustment whatsoever was required.

ACKNOWLEDGEMENTS

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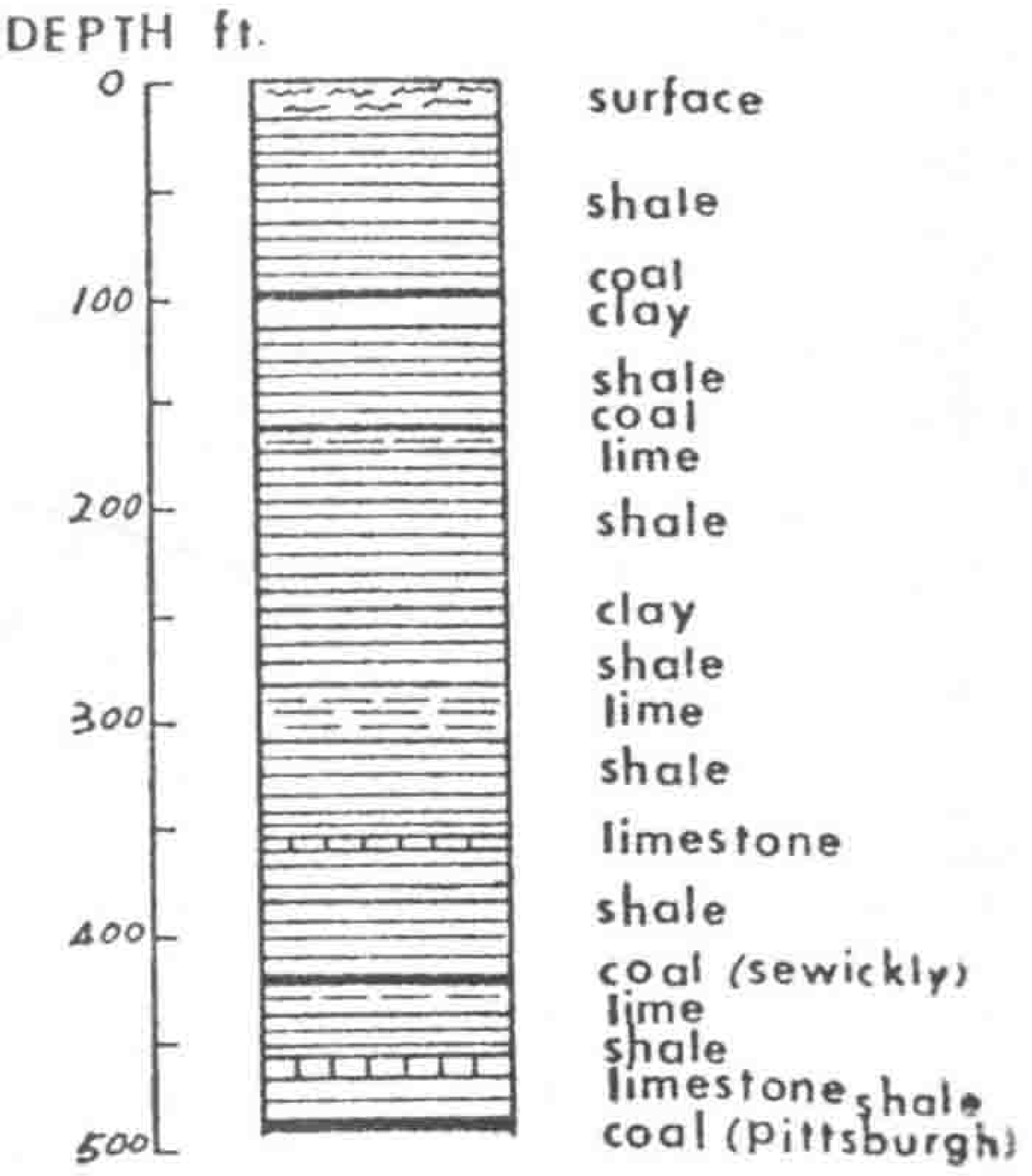

Fig. 1 TYPICAL STRATIGRAPHIC COLUMN

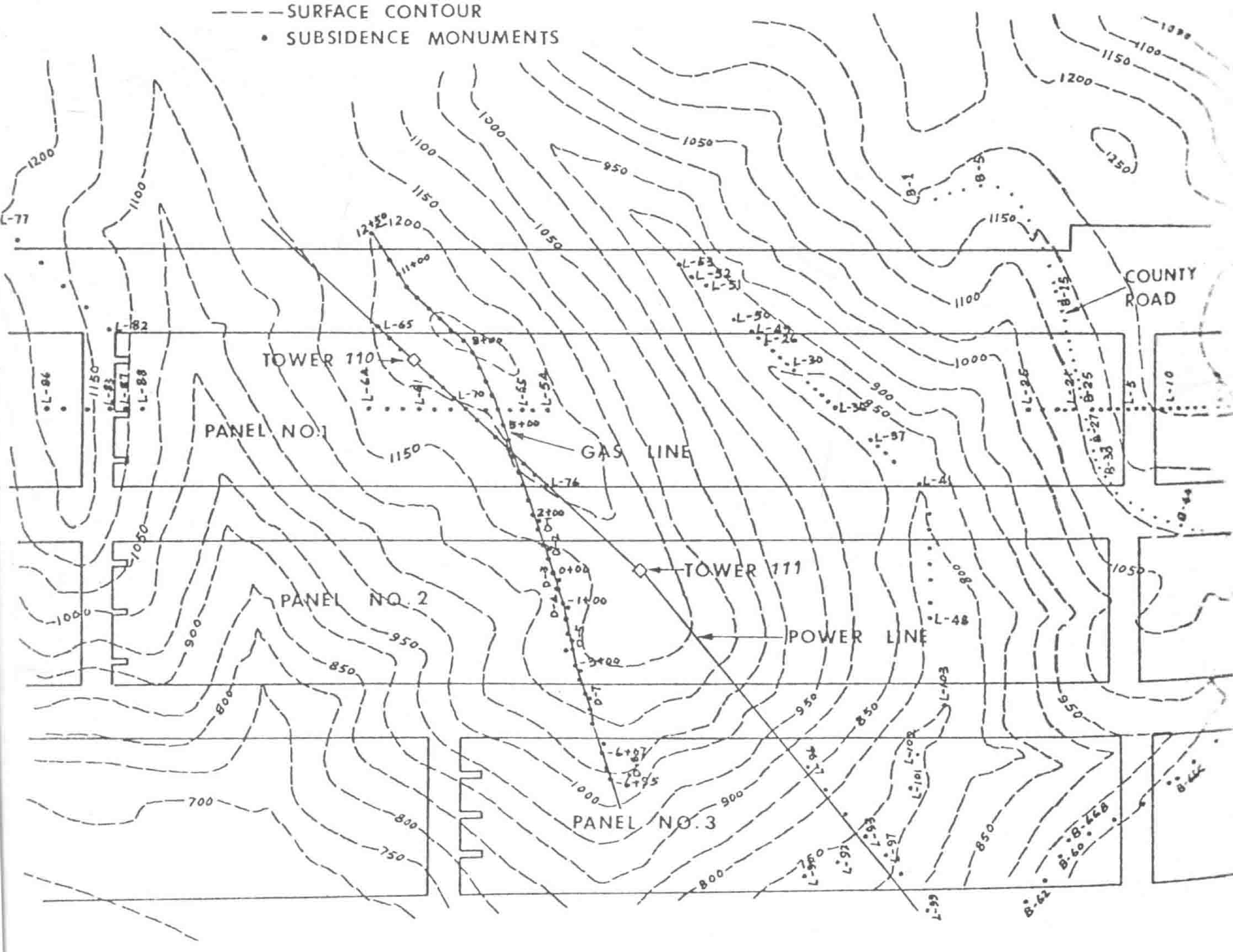

Fig. 2 Overall Longwall Layouts and Subsidence Monitor Plans

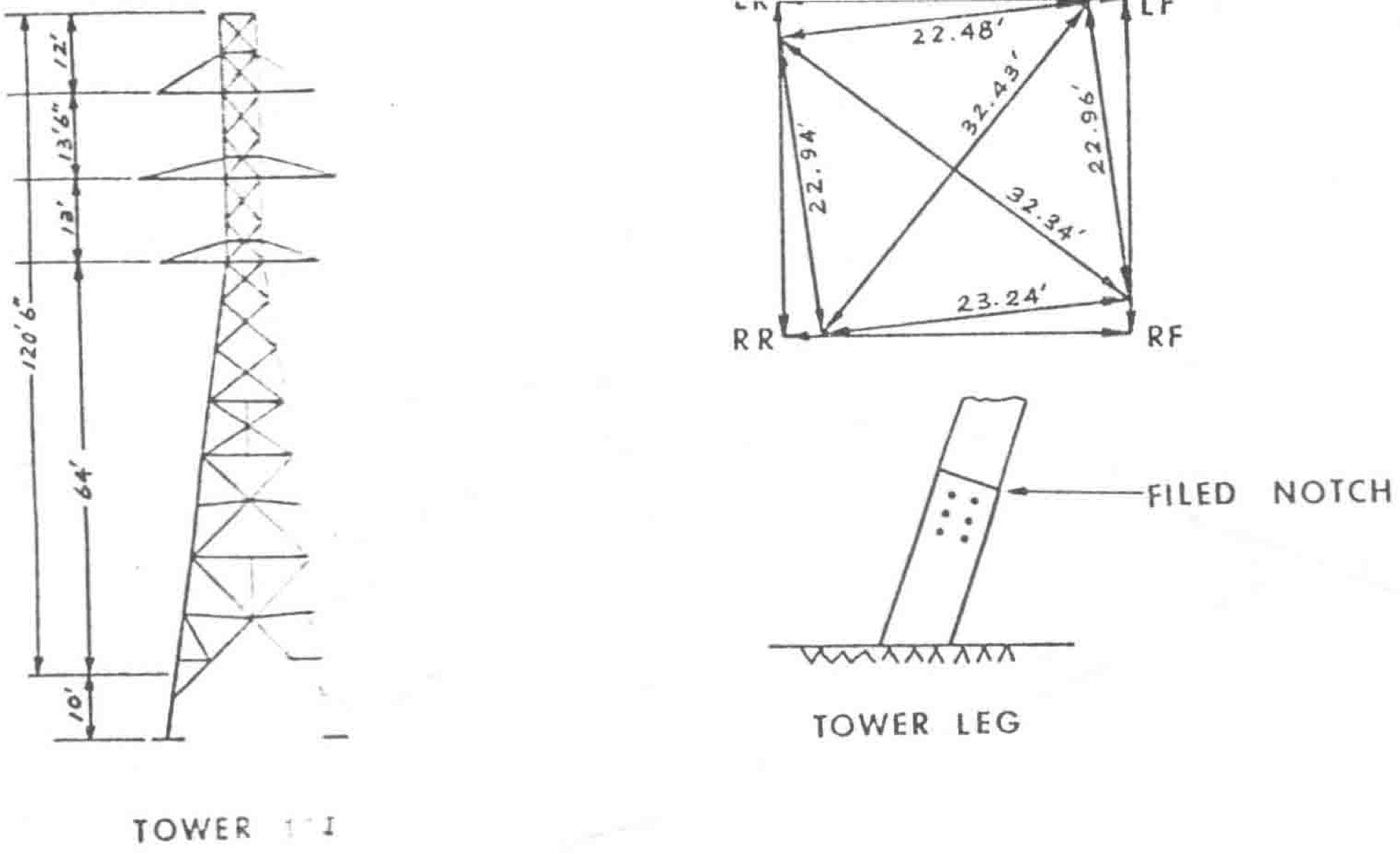

Fig. 3 Cross-sectional View of Angle Tower and Subsidence Monitor Plans

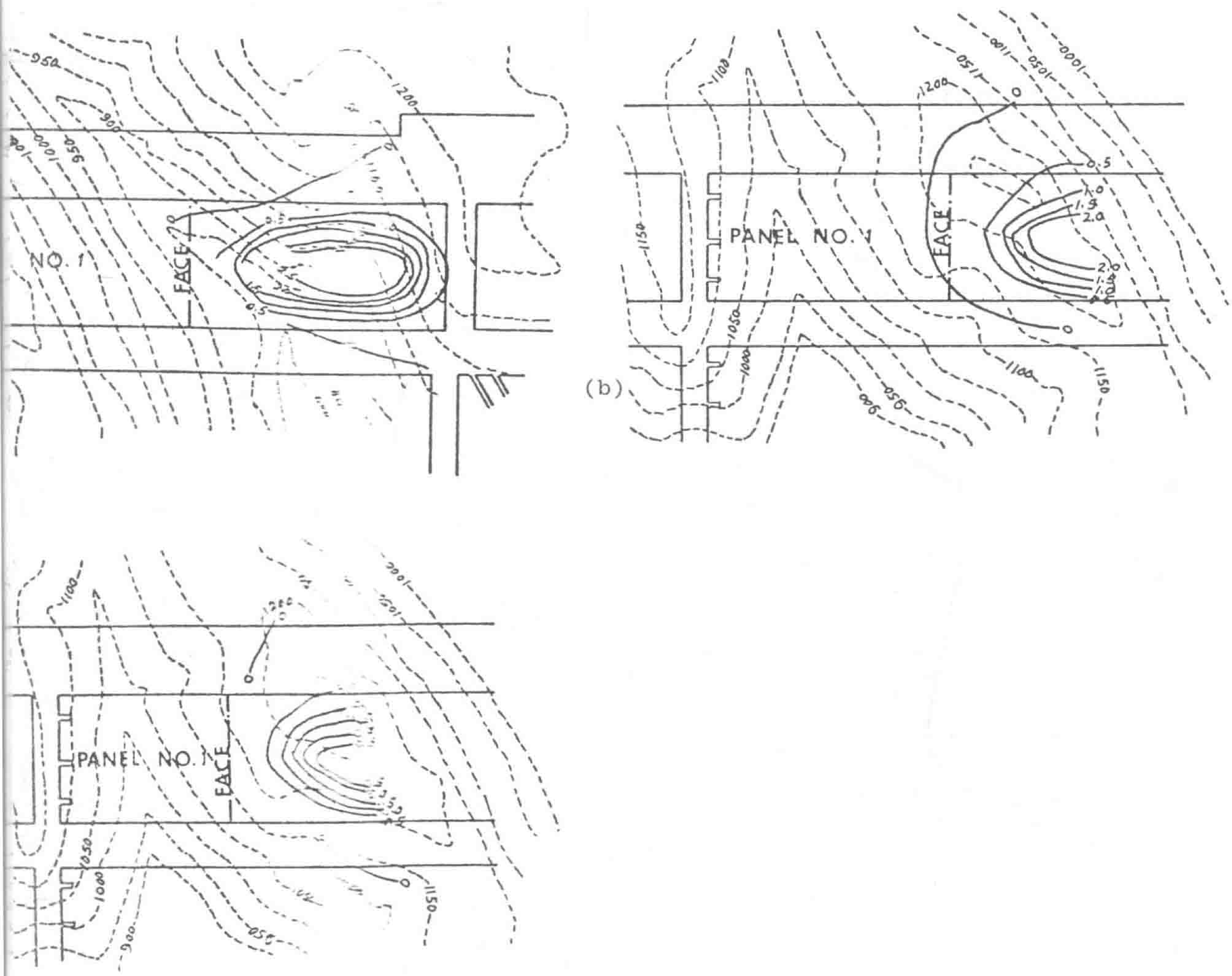

Fig. 4
Development of Subsidence Contours in the First Panel at Various Face Locations

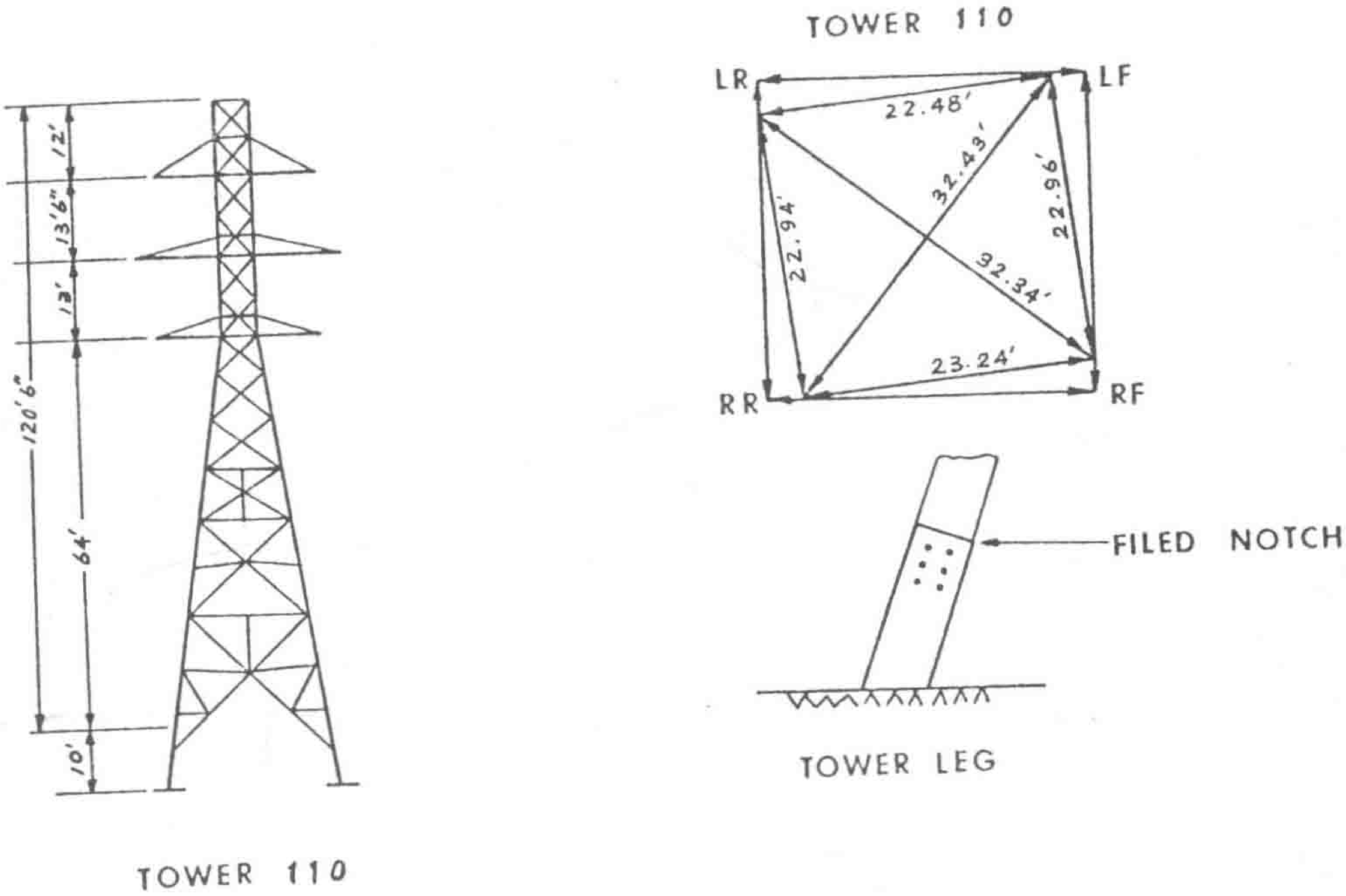

Fig. 3 Cross-sectional View of Angle Tower and Subsidence Monitor Plans

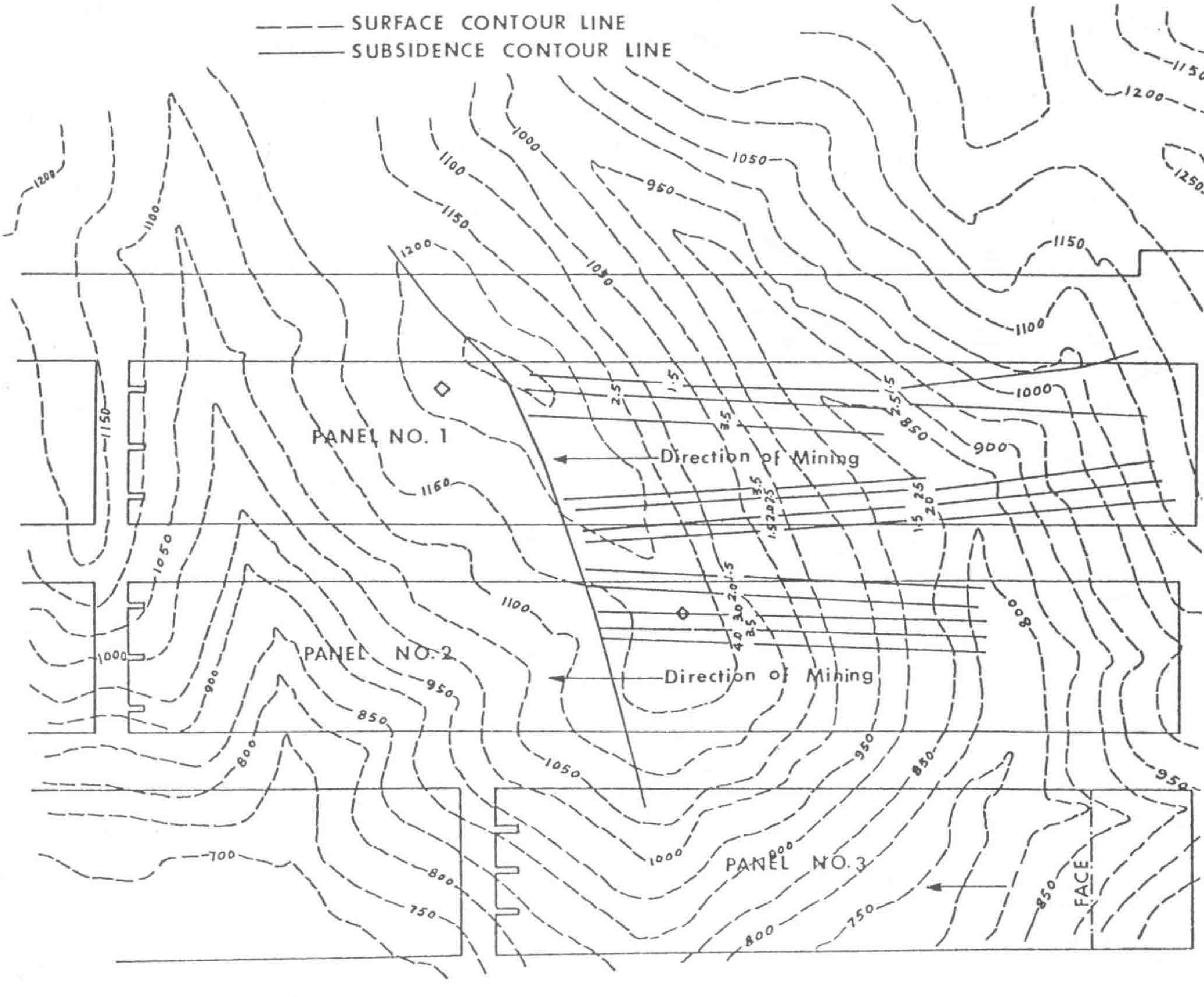

Fig. 5

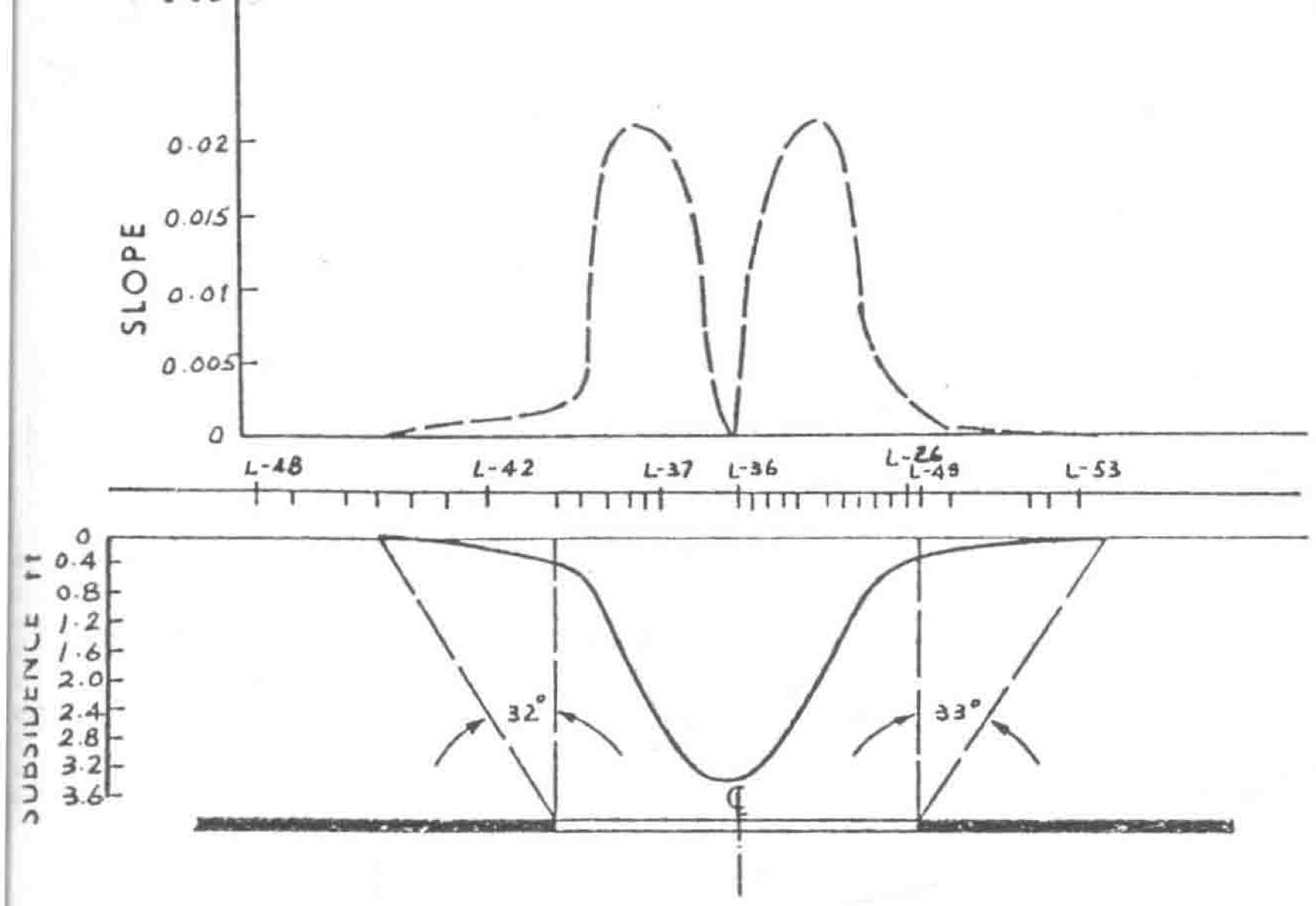

Fig. 6 TYPICAL FINAL SUBSIDENCE PROFILE AND SLOPE PROFILE ALONG VALLEY

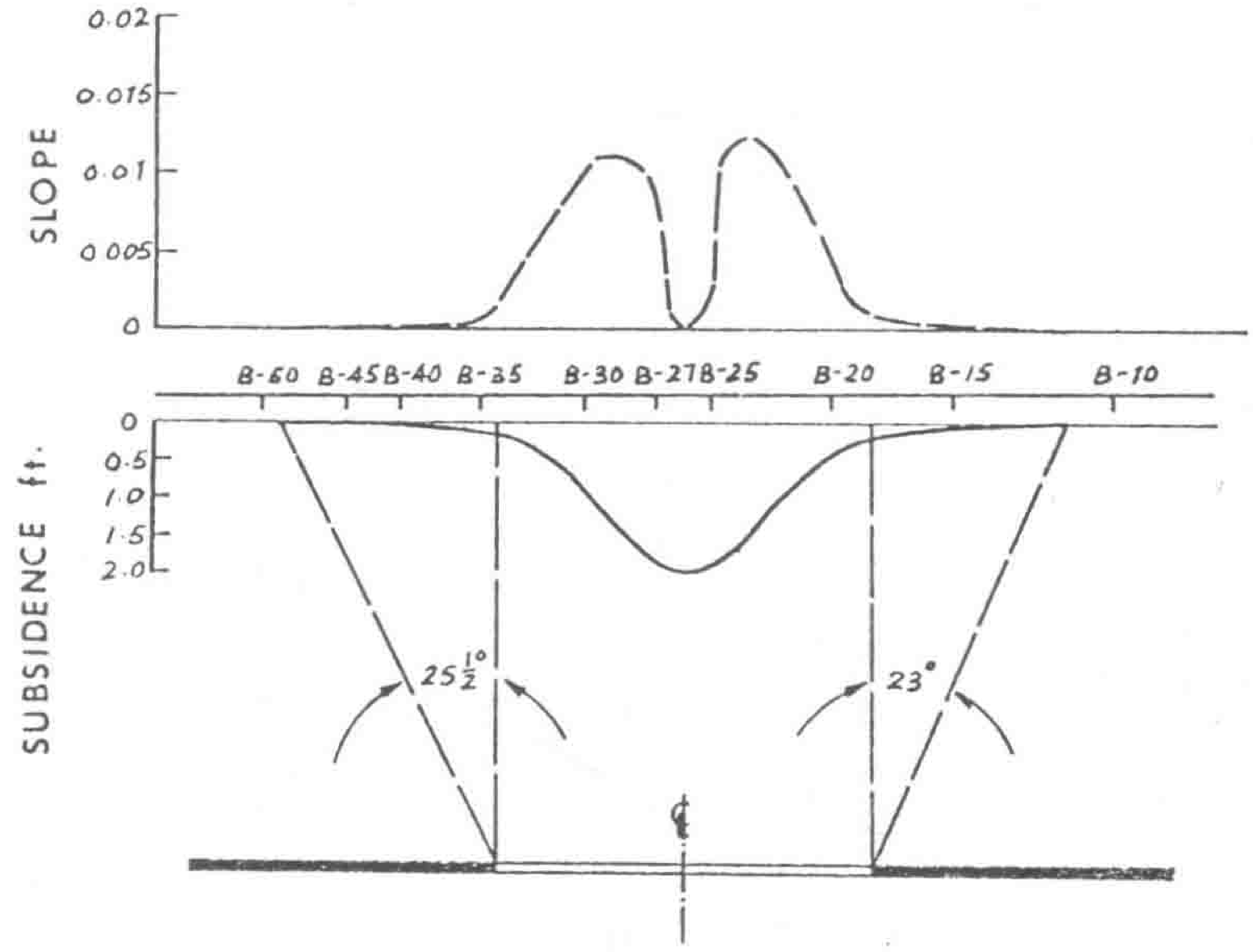

Fig. 7 TYPICAL FINAL SUBSIDENCE PROFILE AND SLOPE PROFILE ALONG COUNTY ROAD

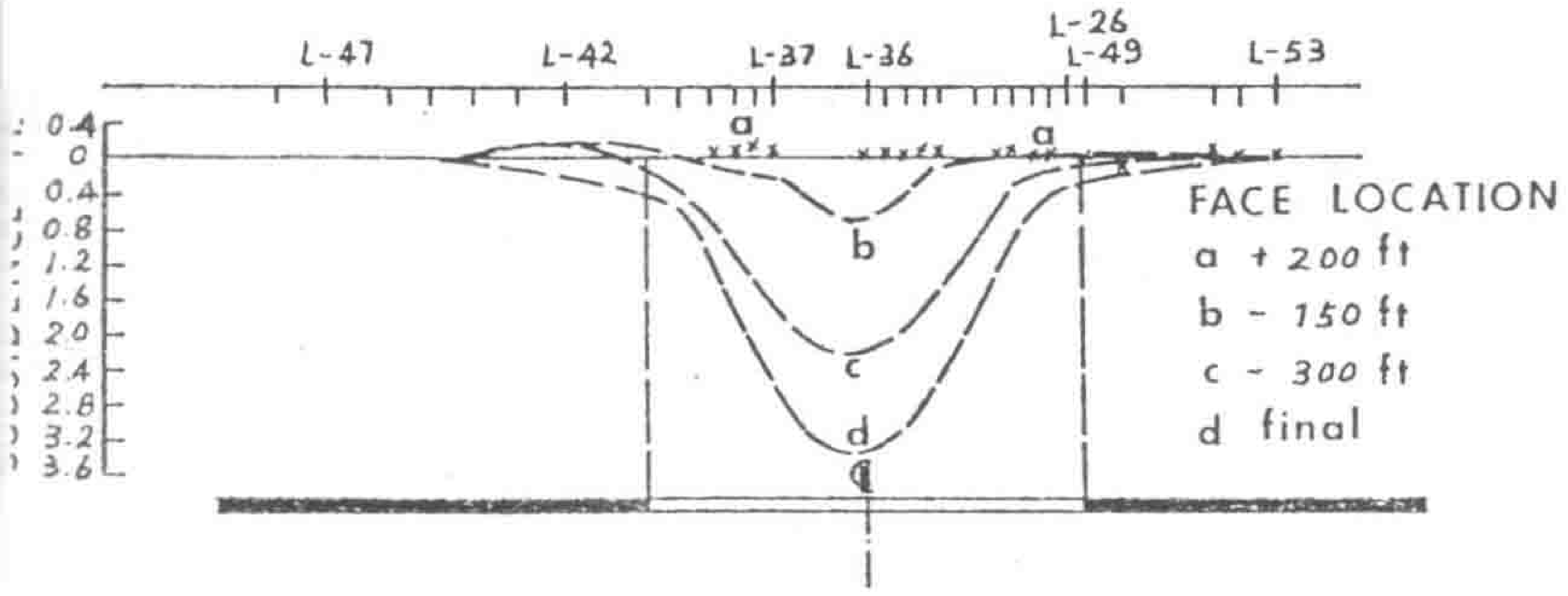

Fig. 8 SUBSIDENCE PROFILE AS A FUNCTION OF FACE DISTANCE

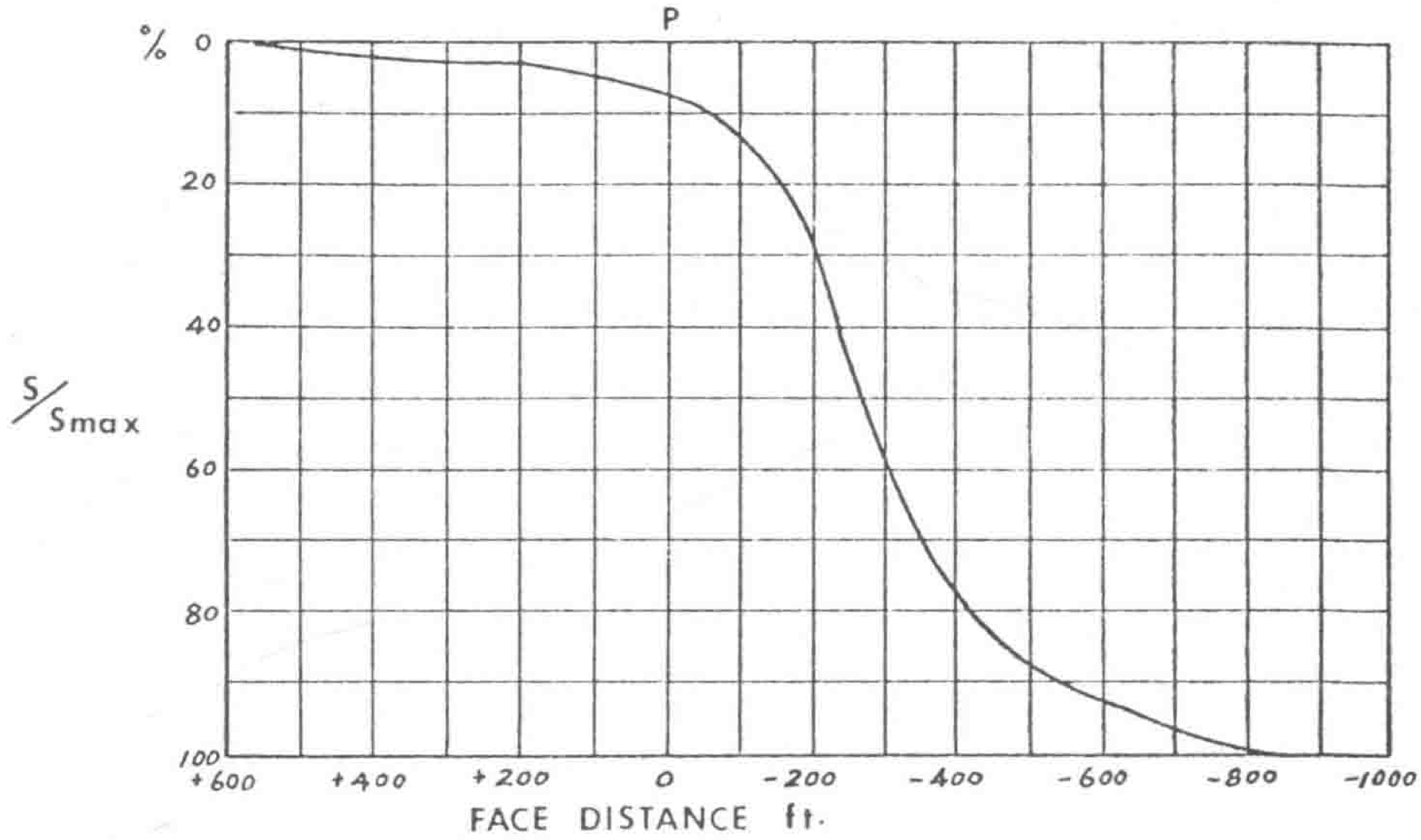

Fig. 9 SUBSIDENCE DEVELOPMENT CURVE

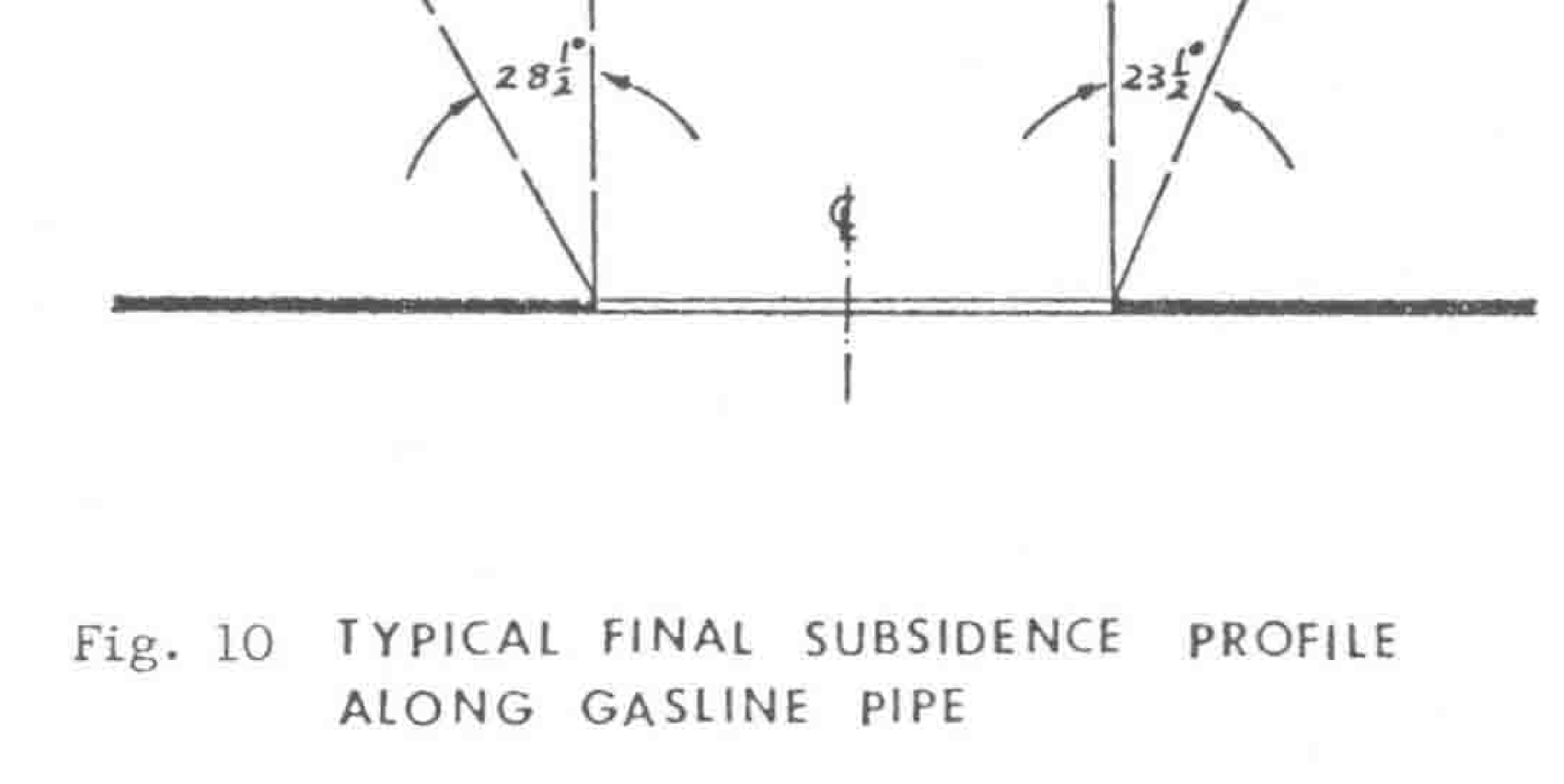

Fig. 10 TYPICAL FINAL SUBSIDENCE PROFILE ALONG GASLINE PIPE

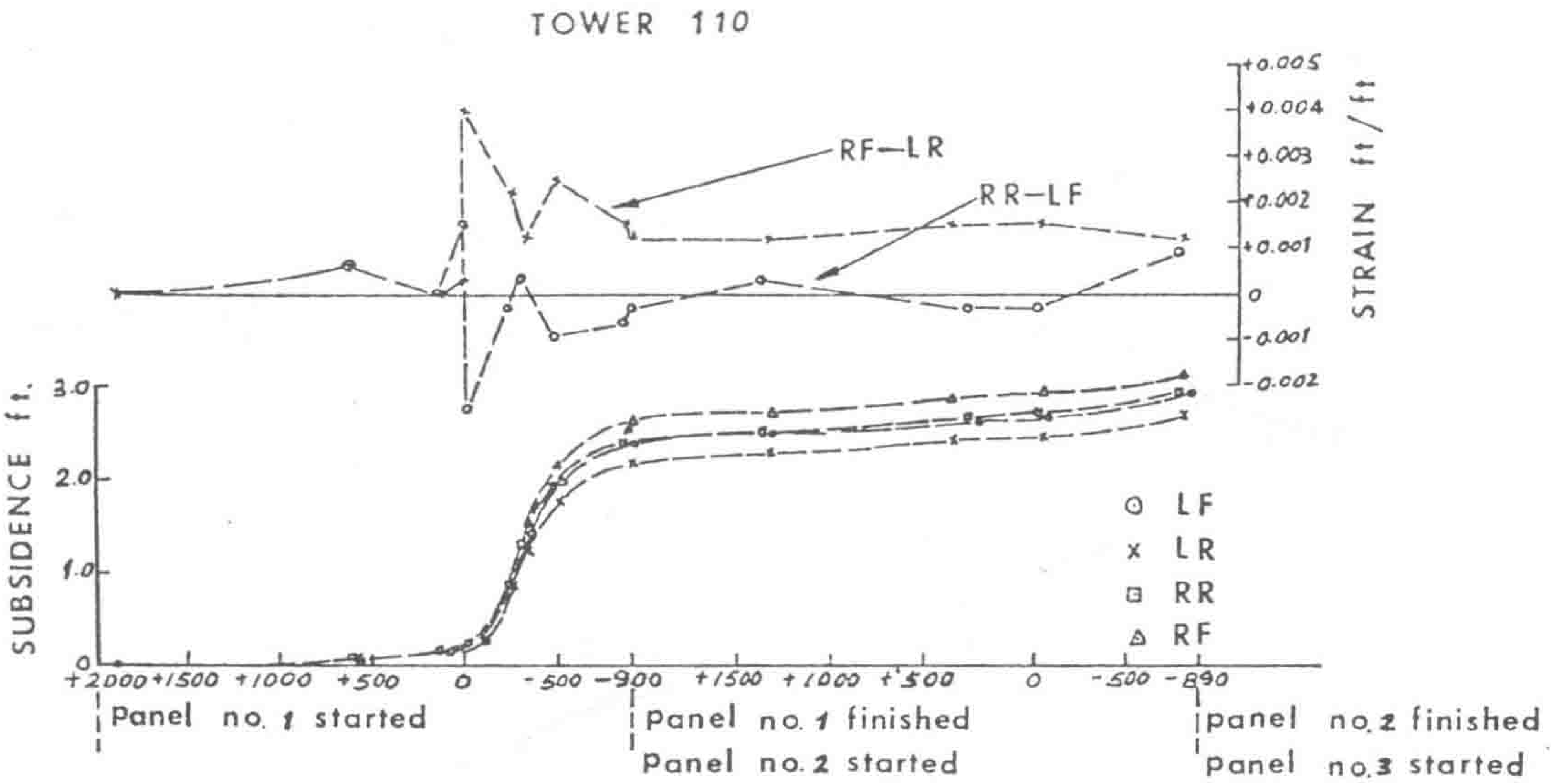

Fig. 11 Measured Subsidence and Strain in Tower 110

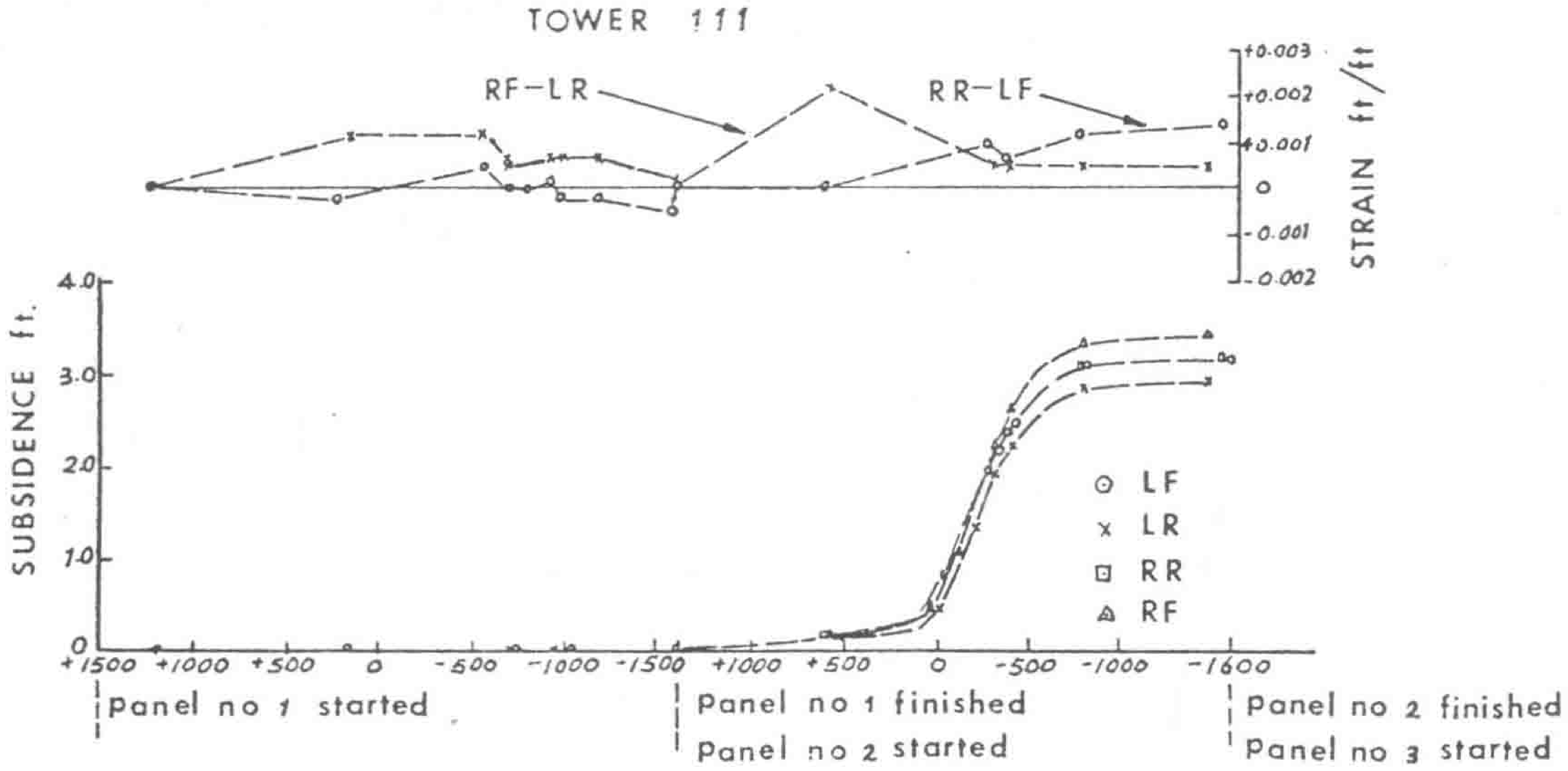

Fig. 12 Measured Subsidence and Strain in Tower 111