624.133 : 621.9

Analysis of the Mechanism of Soil Cutting*

(2nd Report. Deformation and Internal Stress of Soil in Cutting)

By Yotaro HATAMURA** and Kenji CHIJIWA***

Deformation and distribution of internal stresses in soil cutting are analyzed by experiment. The variable parameters are kinds of soils (dry quartz sand and plastic loam) and cutting conditions (cutting angle, cutting depth of cut and cutting speed).

Sand always shows shear type of chip, and loam generally shows flow type. In both kinds of soils, a flat shear-plane appears. And the angle of shear-plane is smaller as the cutting angle increases.

The distribution of internal stresses in soil is measured by internal stress cells. Its idealized pattern is as follows. The maximum principal stress trajectories (compressive) issue in parallel from the surface of cutting blade. Only the trajectories which issue from the cutting edge diverge abruptly. The minimum principal stress in front and lower parts of cutting edge is negative (tensile) under certain circumstances.

Many kinds of cutting phenomena and important things for earth-moving machines are explained from the conception of internal stress.

1. Introduction

In the 1st report, the following things became clear from the experiment of "Cutting patterns of soils"⁽¹⁾: (i) Three typical patterns (shear type, flow type and tear type) of chip appear in soil cutting. (ii) They are closely related to their shear and tensile failure conditions. (iii) And their relations are explained from the internal stress distribution in soil.

Then, the following dynamic quantities of cutting phenomena must have their behaviors clarified by experiment; i.e. how do (i) the deformation of soil, (ii) distribution of internal stresses in soil, (iii) distribution of stresses on a cutting blade and (iv) cutting force change when (i) kinds of soil and (ii) the cutting conditions (cutting angle, depth of cut and cutting speed) change?

In this 2nd report, the experiment of soil cutting is outlined. The results of the experiments of deformation by soil cutting and distribution of internal stresses in soil are also described. Other results of the experiment (stress distribution on cutting blade and cutting force) will be described in the next 3rd report.

2. Outline of the experiment of soil cutting

2.1 Apparatus of the experiment

The apparatus used in the experiment is schematically shown in Figs. 1 and 2.

The mechanism of the apparatus is as follows. A cutting blade cuts soil which is placed in a soil bin. The cutting blade is attached to a sliding frame by load cells. The sliding frame is pushed by a hydraulic

cylinder and moves horizontally along guide rails.

14 pressure cells and 13 friction cells are disposed in two center files on the cutting blade face and detect pressures and frictional stresses acting on the cutting blade respectively. Tracers and internal stress cells are buried in soil to detect the internal stress distributions in soil. By the way, the cutting blade is a plate about 330 mm wide, 200 mm long and 10 mm thick made of steel.

Outputs of load cells, pressure cells, friction cells and internal stress cells are gathered in a terminal

Fig. 1 Outline of the experiment of soil cutting

Fig. 2 Photograph of the apparatus of soil cutting

* Received 11th October, 1973

** Associate Professor, Faculty of Engineering, University of Tokyo

*** Professor, Faculty of Engineering, University of Tokyo, Bunkyo-ku, Tokyo

Table 1 Characteristics of soils used in the experiment

(a) Dry quartz sand	(b) Plastic loam
Name: "Chikuma" quartz sand #6 Characteristics of soil constituent: Distribution of grain size are shown in the following graph	Name: "Tachikawa" loam Characteristics of soil constituent: Distribution of grain size are shown in the following graph

<p>Mean grain size 0.2 mm</p> <p>Water content 0.2%</p> <p>Failure condition $\tau=0.78\sigma$ ($\phi=38^\circ$) (by tri-axial compression test)</p> <p>Unit weight $\rho=1.46 \text{ g/cm}^3$</p> <p>Specific gravity of soil constituent $\rho=2.67$</p>	<p>Plastic limit 24.6%</p> <p>Liquid limit 58.9%</p> <p>Water content 32.9%</p> <p>Failure condition $\tau=0.16+0.11\sigma \text{ kg/cm}^2$ ($c=0.16 \text{ kg/cm}^2$, $\phi=6^\circ$) (by undrained tri-axial compression test)</p> <p>Unit weight $\rho=1.83 \text{ g/cm}^3$</p> <p>Specific gravity of soil constituent $\rho=2.71$</p> <p>Degree of saturation 92.1%</p>

box and connected with bridge heads, dynamic strain amplifier and electro-magnetic oscillograph. Thus, all outputs are measured. Deformation of soil and positions of tracers are photographed through a glass plate installed to the side of the soil bin.

2.2 Measured items

The following dynamic quantities are measured in the experiment of soil cutting in the soil bin:

- (1) Deformation of soil; direction of shear plane.
- (2) Distribution of internal stresses; magnitudes and directions of principal stresses.
- (3) Distribution of stresses on the cutting blade face; pressure and frictional stress.
- (4) Cutting force; magnitude and direction of cutting force and distance from the cutting edge to its application point.

2.3 Soils used in the experiment

2 kinds of soils, i.e. dry quartz sand and plastic loam, are used in the experiment. Their soil-mechanical characteristics are shown in Table 1.

Reasons why dry quartz sand (hereafter shortened to sand) and plastic loam (hereafter shortened to loam) are selected as the subject of the experiment, are as follows:

- (1) They are typical soils showing shear type and flow type of chip from the viewpoint of cutting pattern. Of course, some soil of tear type must be investigated. But it is difficult to compact soil to the extent showing tear type and to measure internal stresses in soil. Therefore, soil which shows tear type is excluded as the subject of the experiment.
- (2) When soils are classified according to their grain size, it seems that loam represents the soil of small size and sand represents the soil of large size.
- (3) Loam and sand nearly represent the soils which appear in actual earth-moving in Japan. Because loam is "Kanto loam" itself which covers the northern and eastern parts of Japan, and sand has similar characteristics to "Masado soil" which covers the western part of Japan in their cutting patterns and failure conditions.

2.4 Variable parameters

It is thought that cutting phenomena are affected by three kinds of cutting conditions (cutting angle,

depth of cut and cutting speed) besides kinds of soils. So these three conditions are selected as variable parameters. Cutting angle* is changed to 30, 45, 60, 75, 90 degrees in five steps. Depth of cut is changed to 5, 10, 15 cm in three steps. Cutting speed is changed to 5, 10, 14 cm/s in three steps.

By the way, the actual conditions of the experiment are chosen as 9 kinds in both cases of sand and loam in order to prevent the increase in times of experiments (Table 2).

2.5 Other conditions

In case of soil cutting by practical earth-moving machines, movement of soil and cutting force are all three dimensional. But in the experiment they are all treated as two dimensional because of their extreme difficulty of theoretical and experimental treatments. So both sides of the cutting blade touch the inner sides of the soil bin when the cutting blade cuts soil. In this case, if frictional stress between soil and the inner sides of the soil bin is negligibly small, it is adequate to treat the experiment of cutting as a problem of plane strain. In the experiments of sand, perfect plane strain condition is not realized because any effective method to decrease the friction between sand and side plates cannot be discovered. But the plane strain condition of loam is nearly realized because some lubricants (sea weed paste and grease) are used to decrease the friction between loam and side plates.

Shapes of soils when cutting starts are shown in Fig. 3. In case of sand, its starting shape is the stationary one that occurs when chip is accumulated in front of the cutting blade. Because, in sand cutting, forces and stresses acting on the cutting blade are much influenced by its shape. In case of loam, the initial surface is made flat to have constant depth of cut and no special device is provided, because it is clear that cutting phenomena are not so influenced by the shape of chip. When sand is to fill the soil bin, it is poured from about 50 cm height for every

*) Cutting angle α is defined as the angle between the cutting blade face (equal to rake face in metal cutting) and horizontal line (reverse direction to the progress of the cutting blade). Therefore, rake angle in metal cutting is expressed by $(90 - \alpha)^\circ$.

Table 2 9 conditions of cutting experimented

Conditions of cutting											
Cutting angle α deg.	30	45	60*	75	90	60	60*	60	60	60*	60
Depth of cut d cm	10	10	10	10	10	5	10	15	10	10	10
Cutting speed v cm/s	5	5	5	5	5	5	5	5	5	10	14
Purpose	Effect of cutting angle				Effect of depth of cut				Effect of cutting speed		

* ; experiment of the same condition

Fig. 3 Shape of soil when cutting starts

experiment. And when loam is to be buried, it is kneaded for every experiment to avoid the influence of age-hardening, and its lump is thrown into the soil bin by the hand. After the initial shape of loam is made up, cutting is carried out immediately.

3. Deformation of soil by cutting

3.1 Method of the experiment

Deformation of soil is photographed by a grid which is marked on the side of soil through the plate glass of soil bin. In case of sand, it is quite difficult to mark on its side in a large soil bin (shown in Fig. 1). And in case of loam, it is also difficult although possible (see 4th report). On the other hand, it is confirmed that deformation in a large soil bin is the same as one in a miniature soil bin (see 1st report). Then the data by a miniature soil bin are used as the data of soil deformation. By the way, the similarity ratio of the deformation in a large soil bin to one in a miniature soil bin is 4:1.

3.2 Result of the experiment

Among the experimental results of deformation of soil by cutting, only the results, both of sand and loam, when cutting angle is changed are shown in Figs. 4 and 5. Other results are omitted on account of space limitation.

3.3 Investigations

(1) Cutting patterns: In case of sand, always shear type of chip appears irrespective of cutting angle and depth of cut. In case of loam, flow type appears irrespective of depth of cut when cutting angle α is larger than 60° . But mixed type of flow and tear appears at $\alpha = 45^\circ$, and tear type appears at $\alpha = 30^\circ$.

(2) Appearance of shear plane: In case of sand, a clear shear plane appears, and continues to slide changing its shape as the cutting blade proceeds. After some proceeding of the cutting blade, the first shear plane vanishes and a new shear plane appears ahead of the old one. Therefore, the appearance of shear plane of sand cutting is intermittent [Fig. 6(a)].

In case of loam, a clear shear plane such as in sand cutting does not appear. The reason is that the shearing zone of loam is much thicker than that of sand. A plane which is obtained by connecting the points where the deformations are the most remark-

(a) Cutting angle $\alpha = 30^\circ$ (b) Cutting angle $\alpha = 45^\circ$ (c) Cutting angle $\alpha = 60^\circ$ (d) Cutting angle $\alpha = 75^\circ$ (e) Cutting angle $\alpha = 90^\circ$

Fig. 4 Examples of deformations of dry quartz sand by cutting

able, may be called "shear plane". This shear plane stays in a constant position relative to the cutting blade irrespective of its proceeding [Fig. 6(b)]. By the way, when $\alpha = 30^\circ$ or 45° , shear plane is not so clear as at $\alpha \geq 60^\circ$.

(3) Direction of shear plane: The shear plane of sand changes its position relative to the cutting blade, but that of loam stays in a constant position. In both cases, transverse section of time averaged one is nearly straight line which issues forwards and upwards from the cutting edge.

Fig. 5 Examples of deformations of plastic loam by cutting

Fig. 7 shows the directions of shear planes which are obtained from the soil deformation in the miniature soil bin. In this figure, in cases of both sand and loam, it is clear that the direction of shear line γ^*

* Direction of shear plane γ is defined as the angle between the shear plane and the direction of proceeding of the cutting blade. Therefore, it is the same as shear angle ϕ in metal cutting. But its notation is set as γ to avoid the confusion with internal friction angle ϕ in this paper.

Fig. 6 Appearance of shear plane produced by cutting

Fig. 7 Direction of shear plane produced by cutting

decreases as the cutting angle α increases, and it increases as the depth of cut d increases. In loam cutting, there is a step in γ -curve between $\alpha = 45^\circ$ and $\alpha = 60^\circ$ when cutting angle α is changed. The reason is that tear type or mixed type of tear and flow appears when $\alpha \leq 45^\circ$, and that pure flow type appears $\alpha \geq 60^\circ$.

(4) Minute shape of shear plane and deformation in other position: In both cases of sand and loam, soils are compressed forwards in front of the cutting blade. And the soil particle which is located under the cutting blade does not suffer a remarkable deformation on both sides (forward and backward) of the cutting blade, but is slightly compressed downwards just in front of the cutting edge. Minutely observed, the shear plane is curved in the downward convex curve in the neighborhood of the cutting edge and linear beyond there. This shape is very reasonable from the viewpoint of the distribution of internal stresses in soil which is explained in the next section (see Figs. 12, 13).

Fig. 8 Immovable part occasionally appearing in front of a cutting edge in dry quartz sand cutting

By the way, in sand cutting, it is occasionally observed that a zone where sand does not move against the cutting edge appears (Fig. 8). (This may be similar to built-up edge in metal cutting.) But this does not always appear, but appears and vanishes with the proceeding of the cutting blade.

From above investigations, the following things are revealed. Sand is cut in shear type and its shear plane appears intermittently. Loam is cut in flow type when cutting angle α is large and its shear plane stays in constant position against the cutting blade, but it is cut in tear type when α is small. In both cases of sand and loam, the transverse section of shear plane may be linear. And the direction of shear plane decreases when the cutting angle increases and it increases when the depth of cut becomes larger.

By the way, more precise investigation (distribution of strains and strain rates in soil) are made in 4th report.

4. Internal stress in soil produced by cutting

4.1 Method of the experiment

Internal stress cells are buried in soil and magnitudes and directions of internal stresses are calculated from their outputs (outputs from three pressure cells and one inclination cell).

The construction of the internal stress cell is shown in Fig. 9. Three pressure cells and one inclination cell are attached to a rubber columnar holder. The inclination cell detects the inclination of internal stress cell itself, and three pressure cells detect pressures acting in each direction. Method to calculate magnitudes and directions of principal stresses from their outputs and their characters is precisely dealt with in another report⁽²⁾.

In order to detect positions of internal stress cells, tracers are buried in soil apart from the measurement by internal stress cells, and cutting is carried out. Their changing positions are measured by photograph (Fig. 10).

Concrete method to bury internal stress cells and tracers is as follows. Before cutting, they are buried at each position whose horizontal distance ahead from the cutting edge is constant (about 40 cm) and vertical height from the bottom of soil bin is fixed. During cutting, positions of tracers are measured at each proceeding of the cutting blade. Thus, positions of internal stress cells are decided, considering they are the same as positions of tracers.

By the way, when outputs from the pressure

Fig. 9 Construction of internal stress cell

Fig. 10 The method of burying internal stress cells and tracers

cells of the internal stress cells are measured, their zero points are defined at their buried situations in soil. So their outputs mean the pressure changes induced by cutting.

4.2 Result of the experiment

Examples of measured data of the internal stress cells are shown in Fig. 11. Characteristics of their data are that outputs of pressure cells and friction cells fluctuate severely in sand cutting but they change very smoothly in loam cutting.

Examples of measured distributions of principal stresses produced by cutting in a large soil bin, both of sand and loam, are shown in Figs. 12, 13. They are the results when only the cutting angle is changed. Other results which are obtained by changing the depth of cut and the cutting speed are omitted on account of space limitation.

By the way, when magnitude of principal stress is determined, coefficient of stress concentration which occurs by inserting the internal stress cell into soil must be considered (detailed in another report⁽²⁾). So the magnitude in sand cutting shown in Fig. 12 is obtained by multiplying the calculated magnitude by 1/2.5. And the magnitude in loam cutting shown in Fig. 13 is a calculated value itself, because in loam cutting the concentration induced by internal stress cell is considered negligibly small.

4.3 Investigations

In both cases of sand and loam, internal stress cells detect internal stresses in soil as the zero points are the situations where self weight of chip is acting. Therefore, distributions of principal stresses shown in Figs. 12, 13 are thought to show the transmission of net stress in soil induced by cutting. Therefore some tensile stresses are shown even in sand cutting. Closely observing sand cutting, it is necessary to make a few corrections of zero point shifts because the magni-

tudes and directions of principal stresses are affected by self weight of sand. But even if these corrections are made, in the neighborhood of shear plane and chip, the magnitudes of principal stress slightly increase and their directions change slightly downward compared with the measured values. Thus the measured values of sand are directly used as correct values in this investigation. In loam cutting, measured values are also directly used because stress change by cutting is much larger than the influence of its self weight.

In both cases of sand and loam, distributions of principal stresses are very similar. And their schematic distribution is shown in Fig. 14. In the zone before and above the cutting blade, both the maximum and minimum principal stresses are compressive and the directions of maximum principal stresses are horizontal or slightly inclined forward (about 20° at most), though they are slightly different in their cutting conditions (cutting angle, depth of cut and cutting speed). It is characteristic that the magnitude of maximum principal stress (compression) on shear plane tends to become large in proportion to the depth in sand cutting, but is nearly uniform irrespective of the depth in loam cutting. These tendencies are shown in Fig. 15 as the distribution of resultant stresses.

Fig. 11 Examples of measured data of internal stresses in soils produced by cutting

zero for the first time at $\alpha = 90^\circ$. From these facts and what is investigated in the previous 1st report, it becomes clear that tear type failure is induced by this tensile stress and flow type appears when this tensile stress is small.

In the zone of shear plane in front of the cutting blade, the directions of maximum principal stresses (compression), both of sand and loam, are horizontal or slightly inclined forward (about 20° at most), though they are slightly different in their cutting conditions (cutting angle, depth of cut and cutting speed). It is characteristic that the magnitude of maximum principal stress (compression) on shear plane tends to become large in proportion to the depth in sand cutting, but is nearly uniform irrespective of the depth in loam cutting. These tendencies are shown in Fig. 15 as the distribution of resultant stresses.

Fig. 12 Examples of measured distributions of principal stresses in dry quartz sand produced by cutting

Though it is necessary to make more precise investigations about distributions of internal stresses in soils besides above qualitative investigations, they are impossible because of the low reliability of the data from the internal stress cells, on account of fatigue and interruption of lead wire caused by violent movement of soil.

From above investigations, the following things became clear about the stress situation in soil induced by cutting. In both cases of sand and loam, the distribution of stresses becomes as shown in Fig. 14, and its shape slightly changes according to its cutting conditions (cutting angle, depth of cut and cutting speed). The magnitude of maximum principal stress along the shear plane is proportional to the depth (or the height of chip accumulated on it) in sand cutting, and is constant irrespective of its depth in loam cutting.

Magnitude and direction of principal stresses

$\times$ 200 g/cm²
 Minimum principal stress (Compression)
 Maximum principal stress (Compression)
 (Arrow indicates tensile stress)

Other cutting conditions:
 Depth of cut $d = 10$ cm
 Cutting speed $v = 5$ cm/s

Fig. 13 Examples of measured distributions of principal stresses in plastic loam produced by cutting

Fig. 14 Idealized distribution of principal stresses in soil produced by cutting

Fig. 15 Idealized distribution of resultant stresses on shear plane produced by cutting

5. Investigations

5.1 Stress field in soil induced by cutting

As the conditions which decide dynamic quantities induced by cutting such as deformation of soil, distribution of internal stresses in soil and distribution of stresses on cutting blade, the following conditions can be mentioned:

(a) As the characteristics of soil: stress-strain relationship, stress-strain rate relationship and failure conditions.

(b) As the boundary conditions: geometrical conditions of cutting (cutting angle, depth of cut and the shape of a cutting blade), frictional condition on blade face and condition of chip's accumulation.

(c) Substitutes for initial condition: cutting speed. Even if these conditions are different, distribution of principal stresses in soil becomes qualitatively as shown in Fig. 14, so long as the cutting blade face is plane and the soil accumulation in front of the cutting blade forms itself into a stationary chip overflowing beyond the top of the cutting blade. The differences of conditions only distort this stress field or change the density of principal stresses.

Concerning the direction of principal stress, irrespective of the differences of dynamic characteristics of soil such as sand and loam, trajectories of maximum principal stresses (compression) issue forward in parallel from the blade face, and only the trajectories which issue from the cutting edge diverge abruptly. Trajectories of minimum principal stress, which intersect trajectories of maximum one, are compressive before and above the cutting edge and are sometimes tensile in the zone under the cutting edge, both in front and back of it. Then, as for the density and number of principal stress trajectories, in the soil whose failure conditions are affected by self weight (corresponding to the theory of internal friction) such as sand, they increase in proportion to the depth from free surface. But, in the soil whose failure condition is not affected by self weight such as loam, total number does not change but the density de-

creases according to the distance from the cutting blade. (This corresponds to the theory of maximum shearing stress. But precisely speaking, loam has an intermediate characteristic between the theory of maximum shearing stress and that of internal friction.)

If the conception of "stress field in soil induced by cutting" is introduced, the following relations are systematically explained; (i) relation between cutting patterns of soils and their failure conditions, (ii) relations of deformation of soil, distribution of stresses acting on the cutting blade and cutting force to cutting condition and failure condition.

About cutting patterns, investigations are already made in the 1st report. And about the deformation of soil, investigations are also made in the section 3.3. Then we try to explain the distribution of stresses acting on the cutting blade using the conception of stress field in soil. In case of sand, required stress to induce sliding on the shear plane is decided by the self weight of sand which is accumulated on the shear plane. So it is understood that pressure and frictional stress are large on the cutting edge, and they decrease with distance to the top of the cutting blade. In case of loam, required stress to induce sliding on the shear plane is not affected by the self weight of loam which is accumulated on the shear plane. Therefore it is expected that nearly uniform pressure and frictional stress are distributed on the cutting blade except that the length of the cutting blade is extremely larger than the depth of cut. And these facts are confirmed by the experiment (see 3rd report).

5.2 Correspondence to actual earth-moving machines

In this experiment, soil cutting is treated as two-dimensional, and the model is much simplified. Therefore, it is difficult to apply the results of this experiment directly to actual earth-moving machines. But, at least, the following important things for them are revealed.

(1) In actual earth moving, few problems occur in sand cutting. But in loam cutting, some problems occur because cutting force is much larger than in sand cutting. The reason is that cutting is made by shear failure of soil. Therefore, it is said that ideal cutting method of such soil is one by tensile failure. On the other hand, in the experiment of loam cutting when the cutting angle α is smaller than 45° , large tensile stress appears in front of and below the cutting edge and it causes the tear type of chip. And in that case, cutting force is much smaller than that which is assumed to cut in flow type (detailed in 5th report). Therefore, in such a case, ideal cutting is realized except that finished surface becomes rough. (This is also realized at $\alpha \geq 60^\circ$ if the friction between chip and blade face is decreased. Details are published in 5th report.) Some new earth-moving method which requires smaller horse power may be realized to some extent by such a phenomenon.

(2) In cutting of such soil as sand, unreasonably large cutting force is required if such cutting method is adopted that cutting chips are accumulated on shear plane. Therefore, in such soil cutting, it is necessary to adopt such cutting method that chips do not stay on shear plane. For this reason, in sand cutting, a scraper is more rational than a bulldozer and moreover, an elevating scraper is more rational than the ordinary one. On the other hand, in cutting of such soil as loam whose failure condition is

scarcely affected by normal stress, the required stress to occur sliding on shear plane is not so influenced by self weight of soil accumulated on shear plane. Therefore the same condition as in sand cutting is not necessary. But, as is above described, decrease of friction on the blade face is much more required for saving horse power.

5.3 Comparison with cutting in other fields

Such experiment as is described in this paper to measure directly internal stress in material cut can not be done in other cutting field such as metal and rock cutting. The reason is that no method of measurement exists to detect internal stress directly.

On the other hand, let us consider the correspondence to metal cutting. As is described in the 1st report, loam is similar in its stress-strain relationship, stress-strain rate relationship and failure condition (stress of shear failure is not affected by hydraulic pressure) to many metals (lead, copper and aluminium), as well as in the distribution of stresses on cutting tool (detailed in 3rd report) and the frictional condition between chip and rake face. Thus it is considered that the distribution of internal principal stresses in soil induced by cutting which is revealed in this experiment is similar to that in many metals. And from above results, some analogies may be made about deformation of material cut and distribution of internal stresses in them.

6. Conclusions

Experiments of the deformation of soil and the distribution of internal stresses in soil which are caused by two-dimensional cutting are carried out. Dry quartz sand (hereafter shortened to sand) and plastic loam (hereafter shortened to loam) are chosen as the subject of the study. In the experiments, the following things are revealed.

(1) Sand is cut in the shear type of chip irrespective of cutting conditions. Loam presents flow type when cutting angle α is large ($\alpha \geq 60^\circ$) and tear type when α is small ($\alpha < 45^\circ$).

(2) In both cases of sand and loam, the transverse section of shear plane is nearly straight line which issues upwards and forwards from the cutting edge. The direction of shear plane r decreases as the cutting angle α increases in both cases of sand and loam. On the other hand, when the depth of cut d increases, r increases in sand cutting but it remains constant in loam cutting.

(3) Distributions of internal stresses in soils induced by cutting are determined by inserting internal stress cells into soils.

(4) In both cases of sand and loam, trajectories of maximum principal stress (compression) issue in parallel from the cutting blade, and only the trajectories which issue from the cutting edge diverge abruptly. Trajectories of minimum principal stress, which intersect trajectories of maximum one, are always compressive before and above the cutting edge where shear plane appears, and are sometimes tensile in the zone under the cutting edge, both in front and back of it. The shape of this distribution of internal principal stresses only distorts or changes the density even when the cutting conditions are changed.

(5) From the investigation of soil deformation and stress distribution in soil, it is made clear that the accumulation of chips and the cutting angle

are important parameters in actual earth-moving equipment.

(6) It is described how the distribution of internal stresses in soil, which is investigated in this study, corresponds to cutting in other fields.

Acknowledgement

The authors are indebted to Prof. N. Takenaka, Assoc. Prof. T. Nagao of Tokyo Univ. and Mr. K. Ogaki of Komatsu Works Co. Ltd., for many valuable suggestions. The authors are also indebted to Mr. T. Takeuchi of Tokyo Univ., Mr. A. Tsuzuku of

Komatsu Works Co. Ltd. and many students of Chijiwa Lab. of Tokyo Univ., who assisted them in the experiments devotedly. All equipments for this study have been made by the members of work shop of Dept. of Mech. Eng. of Tokyo Univ..

References

- (1) Y. HATAMURA, K. CHIJIWA, Bulletin of the JSME, 18-120 (1975) 619 ~ 626
 - (2) K. CHIJIWA, Y. HATAMURA, Bulletin of the JSME, 15-82 (1972) 455 ~ 465
-