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労働安全衛生総合研究事業

斜面崩壊による労働災害防止に関する研究

平成17年度　総括研究年度終了報告書

主任研究者　三田地　利之

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主任研究者　三田地　利之　北海道大学　大学院　教授

研究要旨：斜面崩壊による労働災害を防止するために，斜面崩壊の防止，および発生の予知に関する研究を行った．当該年度は，掘削による斜面の崩壊および降雨による斜面地盤の地下水位の上昇に関する研究を行った．

A. 研究目的

斜面崩壊の事故を防止するために，崩壊の防止およびその予知についての研究を行う．

B. 研究方法

降雨による斜面崩壊のメカニズムを明らかにするために，遠心力載荷実験において，砂質土による模型地盤を作成し，不飽和土における降雨による地中の間隙水圧の挙動について調べた．

C. 研究結果

遠心力を模型地盤に与えることにより，地盤上部が不飽和土，下部は飽和地盤を再現することができた．遠心力の増加によって地下水以下の間隙水圧は静水圧分布となっていることが確認できた．地下水面より上の地盤は，遠心力の増大によって必ずしもサクションは増加していないことがわかった．

降雨によって，地下水面より上のサクションは消散し有効応力が現象することが確認できた．また，降雨強度と地下水位の上昇速度の関係を実験的および理論的に求め，理論的な方法は十分な精度があることが確認できた．

遠心力載荷後，地盤を解体し含水比の分を測定した．この含水比の分布と，室内試験で求めた水分保持曲線との間に良い一致が認められた．

D. 健康危機情報

なし

E. 研究発表

1．論文発表

なし

2. 学会発表

遠心場における不飽和土地盤の挙動：地盤工学会北海道支部

遠心力模型実験による降雨時の地下水位の変動：地盤工学会全国大会

F. 知的財産権の出願・登録状況

1．特許取得

なし

2．実用新案登録

なし

3．その他

なし

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（総括）研究年度終了報告書

斜面崩壊による労働災害防止に関する研究

分担研究者　田中　洋行　北海道大学　大学院　助教授

研究要旨：斜面崩壊による労働災害を防止するために，斜面崩壊の防止，および発生の予知に関する研究を行った．当該年度は，掘削による斜面の崩壊および降雨による斜面地盤の地下水位の上昇に関する研究を行った．

A. 研究目的

斜面崩壊の事故を防止するために，崩壊の防止およびその予知についての研究を行う．

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降雨による斜面崩壊のメカニズムを明らかにするために，遠心力載荷実験において，砂質土による模型地盤を作成し，不飽和土における降雨による地中の間隙水圧の挙動について調べた．

C　研究結果

遠心力を斜面地盤に負荷し，降雨を与えることにより，斜面内の地下水位上昇を捉えた．実験は降雨強度と遠心力を変化させ，地下水位の上昇速度との関連を試みた．

同一Gでは，降雨強度が大きいほど，地下水位の上昇速度が大きくなる．地下水位は，降雨によって地表面から流入する水量と，地下水位の高低差に起因する水平移動の相互作用によって決まると考えられるが，降雨強度が水平移動より大きければ，水位は上昇する．この考え方の妥当性が実験によって確認できた．同様に，同じ降雨強度でも遠心力が大きいと，水平移動による水量が多くなるので，上昇速度が小さくなる．これも実験によって確認することができた．

D　健康危機情報

なし

E　研究発表

1．論文発表

なし

2　学会発表

遠心力載荷試験による砂質土斜面崩壊メカニズムについての研究，地盤工学会北海道支部

遠心力載荷試験による砂質土の斜面崩壊の再現，地盤工学会全国大会

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(総括) 研究年度終了報告書

斜面崩壊による労働災害防止に関する研究

分担研究者　豊澤康男 独立行政法人産業安全研究所 主任研究官

研究要旨：斜面崩壊による労働災害を防止するために，斜面崩壊の防止，および発生の予知に関する研究を行った．当該年度は，掘削による斜面の崩壊および降雨による斜面地盤の地下水位の上昇に関する研究を行った．

A 研究目的

斜面崩壊の事故を防止するために，崩壊の防止およびその予知についての研究を行う．

B 研究方法

中規模模型斜面を作成し，掘削によって地盤がどのように崩壊するかを明らかにした．

C 研究結果

中規模斜面模型を砂質土によって作成し段階的に掘削を行い，地盤を破壊に至らしめた．斜面上に変位計を取り付け，その動きを観測し，崩壊の前兆挙動を捉えた．その結果，斜面が大幅に崩壊する時には，その直前に地盤は特異な変形が生じることがわかった．これは，実際の施工現場に応用することにより，事前に斜面崩壊を探ることができ労働者を非難することが可能となる．

円弧すべりプログラムによって，破壊時の地盤の安全率を計算した．その結果，破壊時の安全率は0.95から1.1の間に入っており，極めて精度の高い結果が得られた．

D 健康危機情報

なし

E 研究発表

1．論文発表

なし

2　学会発表

Development of Tilt-sensor and possibility of measurement of failure trend just before the failure, Proc. of the International Symposium.

F 知的財産権の出願・登録状況

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斜面崩壊の事故を防止するために，崩壊の防止およびその予知についての研究を行う．

B 研究方法

遠心力載荷実験によって斜面地盤を再現し，掘削によって地盤がどのように崩壊するかを明らかにした．

C 研究結果

遠心力載荷実験によって斜面模型を砂質土によって作成し，別途に行った中規模斜面実験との対比を試みた．遠心加速度は10G 程度の値を用いた．また，遠心載荷中に掘削を可能とするために，遠隔操作による地盤掘削装置を開発した．この装置によって，遠心中においても，掘削が可能となり，当初予定されていた実験を終了することができた．

斜面の破壊および破壊に至るまでの地盤の動きは中規模模型と同様な値が得られ，このような斜面の実験においても遠心力載荷装置が有効であることがわかった．

D 健康危機情報

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E 研究発表

1．論文発表

なし

2　学会発表

Failure mechanism of slopes in the centrifuge using in-flight excavator, Proc. of the International Symposium.

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1 特許取得

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研究成果の刊行に関する一覧表

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笠間大樹・田中洋行・S.B.Tamrakar・豊澤康男："遠心力載荷試験による砂質土の斜面崩壊の再現"，地盤工学研究発表会講演集（掲載予定），2006.

International Symposium
Landslide Hazard in Orogenic Zone from the Himalaya to Island Arc in Asia
25-26 September, Kathmandu, Nepal
Proceedings, pp. 255-264

FAILURE MECHANISM OF SLOPES IN THE CENTRIFUGE USING IN-FLIGHT EXCAVATOR

S.B. Tamrakar[1)], Y. Toyosawa[2)], K. Itoh[3)], N. Horii[4)] and S. Kusakabe[5)]

ABSTRACT

In this paper, failure mechanism of slopes during the excavation of lower portion of the slope (toe) is described. Model slopes of volcanic soils were prepared within the centrifuge and the slope was excavated using an in-flight excavator which could work within the centrifugal environment. Three types of statically compacted model slopes (100, 150 and 200 kPa) and two types of excavation pattern (toe excavation with or without trench excavation at the beginning) were studied. Direct contact type linear variable differential transducers (LVDT) were installed on the slope and on the top surface (crest) of the models to observe the deformation behaviour during the excavation. Circular slope failure was observed in all the cases. It was observed that the critical height of the slope before failure increases with the increase in the compaction pressure. In addition, if the excavation of toe of the slope is done with trench excavation at first, the critical height of the slope could be reduced in comparison to the excavation of toe without trench at first. From the deformation-elasped time graph, 2nd and 3rd degree creep could be distinguished which might be helpful in the predicting the slope failure time.

KEYWORDS: toe excavation, centrifuge, in-flight excavator.

INTRODUCTION

Slope failure of the natural slopes occurs either due to natural phenomenon (rain. earthquake, etc.) or due to the manual construction works (excavation, embankment, etc.). To protect the slopes, either they are excavated up to the stable (safe) slopes or gravity retaining walls are made or other slope protection methods are followed. Slopes become safe once any of the previously mentioned protective works are done. But during the process of protection works, it is necessary to cut or excavate the slopes and these are at a higher risk of failure. Most of the accidents take place during such excavation and it was reported in Japan that 32 lives were lost due to such slope failure accidents in the year 2003. Fig. 1 shows one of such sites (Bandai-mountain of Fukushima, Japan) where such slope failure accident took place. Slope failure in this site took place when the toe of the slope was excavating in order to construct a retaining wall. In order to prevent the slope failure during such excavation works one should understand the failure mechanism of slope so that a safe and economical method of excavation work could be done.

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In this research, failure mechanism of slopes during the excavation of lower part (toe) of the slope is studied with the consideration of trench excavation at the toe before or after the toe excavation at different soil strength using an in-flight excavator machine which could be used in the centrifugal environment.

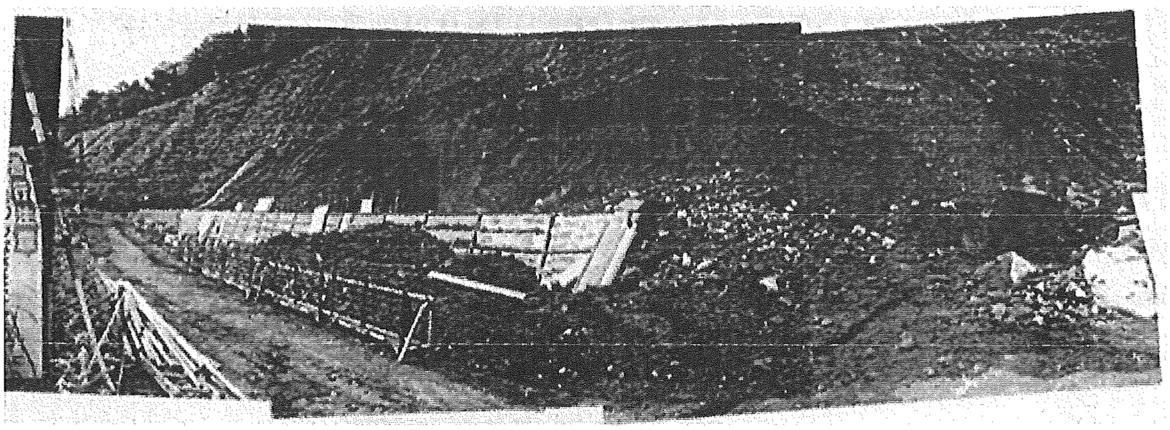

Fig. 1 Slope failure due to excavation

EXPERIMENTAL SET UP

In this experiment, soil samples are collected from the above mentioned slope failure accidental site. This soil is classified as SV (Sandy, Volcanic Ash). Grain size distribution is shown in Table 1. Standard compaction test is also performed and its results are shown in Fig. 2. Model ground is prepared in a model box (Fig. 3) with static compaction using bellofragm cylinder. Inner size of the model box is as follows: 45 cm x 15 cm x 27.2 cm. Model ground is prepared by compacting soil into 12 layers; each layer is of 2 cm thick and it is compacted for 5 minutes. Kaoline is spread in between each layer. This facilitates to observe the failure plane and hence failure pattern. In addition, thickness of each layer could also be confirmed.

Table 1: Grain size distribution of Volcanic Sand

Sand (0.075~2mm) %	81.2
Finer particles (< 0.075mm) %	18.8
Silt (0.005~0.075mm) %	12.4
Clay (< 0.005mm) %	6.4
Max. diameter of particle mm	2.0
Uniformity coefficient (D_{60}/D_{10}) U_c	18.2
Classification	SV

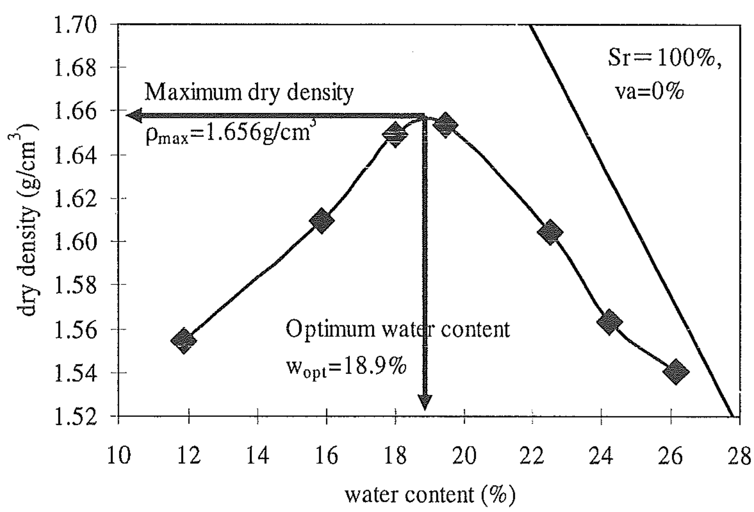

Fig. 2 Compaction curve

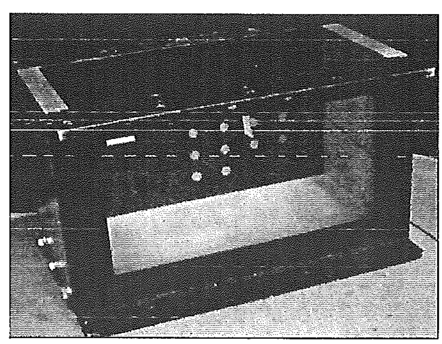

Fig. 3 Model box

Water content of the sample is maintained around 18% which is closer to its optimum moisture content (18.9%). Model ground is prepared under three compaction pressures; 100, 150 and 200 kPa. Once the model ground (45 cm x 15 cm x 24 cm) is taken out from the apparatus box, its front and back panels are removed and the model ground is cut in to the 60° slope angle. Final shape of the model ground is shown in Fig. 4 and 5. The slope angle referred here is according to the safety guideline given out by the Labour Safety and Health Regulation.

Once the model slope is ready, then the side panels; with glass (Fig. 6) and without glass were attached to the model slope ground. In order to reduce the friction between the model ground (soil) and the model box panels, rubber membrane is placed in between. This rubber membrane (Fig. 6) is of same size as that of the model slope ground. Also, a thin film of silicon grease is applied in between the membrane and the panels. More friction could be reduced with it. Finally, whole the model box and model ground are moved down into the platform of the centrifuge.

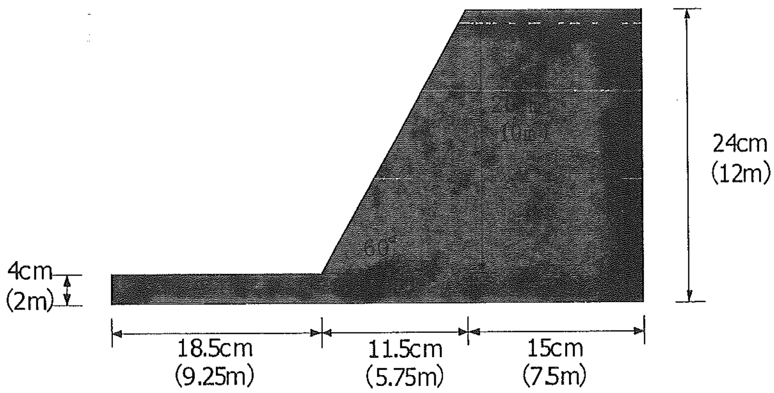

Fig. 4 Final Mod ground (nos. in side the bracket represent the real dimensions when run under 50G)

Direct contact type deformation transducers (LVDTs) are placed on the slope and on the top surface of the slope as shown in Fig. 7. Location of each LVDT is marked by × sign. Two LVDTs (S1 and S2) are placed on the slope and another 5 LVDTs (V1, V2, V3, V4 and V5) are put on the top surface. Once the set up is finished, the whole model box is placed on the swinging platform of the centrifuge.

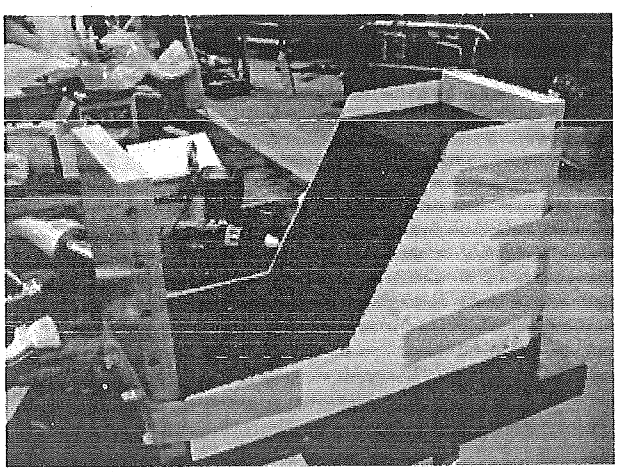

Fig. 5 Model Slope ground

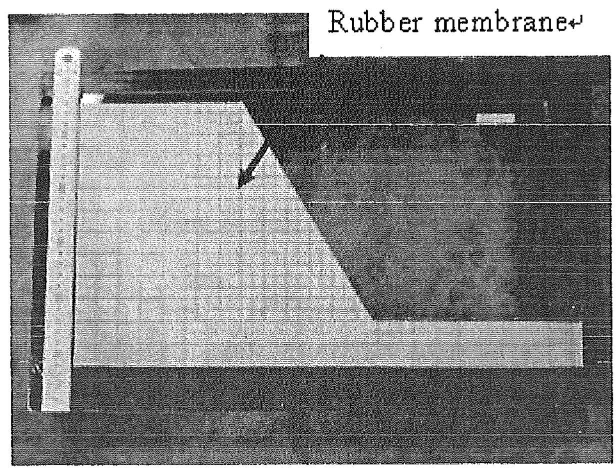

Fig. 6 Rubber membrane on the glass pan

MARK-II CENTRIFUGE

Mark-II centrifuge (Fig. 8) is the new type of effective and multifunctional medium sized centrifuge, which was reconstructed in National Institute of Industrial Safety, Tokyo, Japan. As in other centrifuges, it consists of a main shaft, a drive unit, two arms, two swinging platforms, a signal and power supply interface and a control box. But unlike in other centrifuges, end portions of its arms are asymmetric. In one end of the arm, solid 'U' shaped structure having a back plate is provided. In this back plate, swinging platform could be fixed as per the requirement by using a pair of hydraulic suspension jacks when the platform is lifted up. This type of system is called "Touch-down system" and it facilitates the simulation of strong earthquake motions in case of dynamic tests (e.g. Shaking table). Other end of the arm is also provided with U-shaped structure without a back plate. This place is used for non-shaking or static tests. Since the back plate is not provide in this side, larger platform, longer arm and a lager working area could be possible. Back plate weight of dynamic side is balanced by hanging counter-weights along the two sides of the static side.

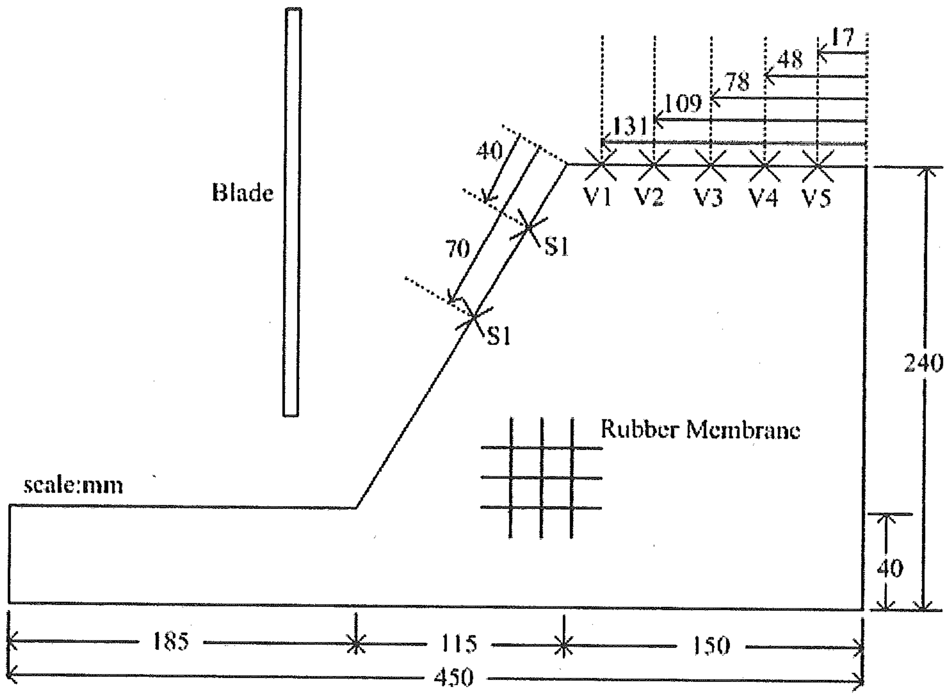

Fig. 7 General layout of the model slope with displacement transducers

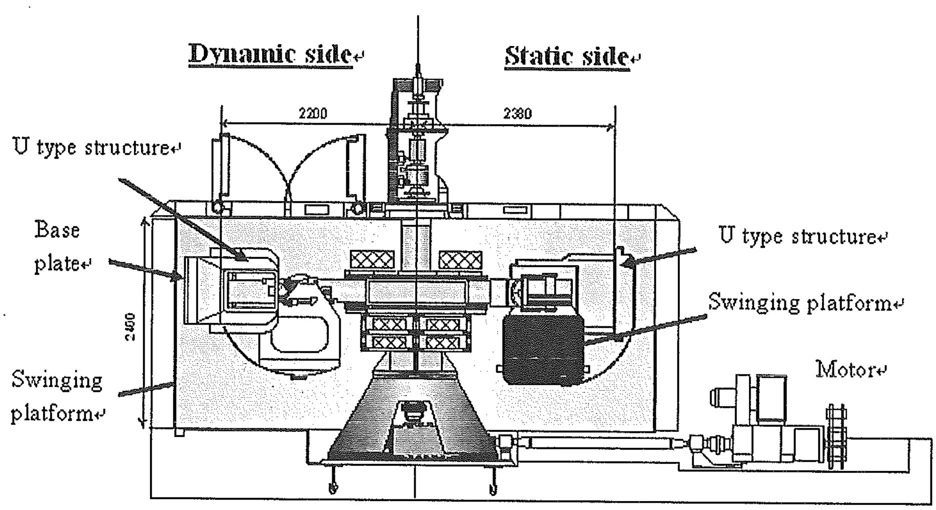

Fig. 8 Mark II centrifuge

In-Flight Excavator

With the change in the stress condition of the ground, its strength and deformation also changes. Therefore, it is necessary to reproduce the actual excavation process in the centrifuge model test also. Various methods of reproducing the process of excavation in the centrifuge model tests were used in the past. For example, cutting up the section, which is to be excavated beforehand from the model ground and then inserting a rubber bag filled up with the liquid at the cut portion and finally, draining out the liquid from the rubber bag during the centrifuge test. But with this method, there was a problem that resistant pressure of passive side can not be reproduced as the excavation section is liquid.

In order to solve this problem Toyosawa et al. (1998) developed an in-flight excavator (Fig. 9) and its specification is given in Table 2. This device is provided with a screw auger which could be used for discharging the excavated soils out side the model box.

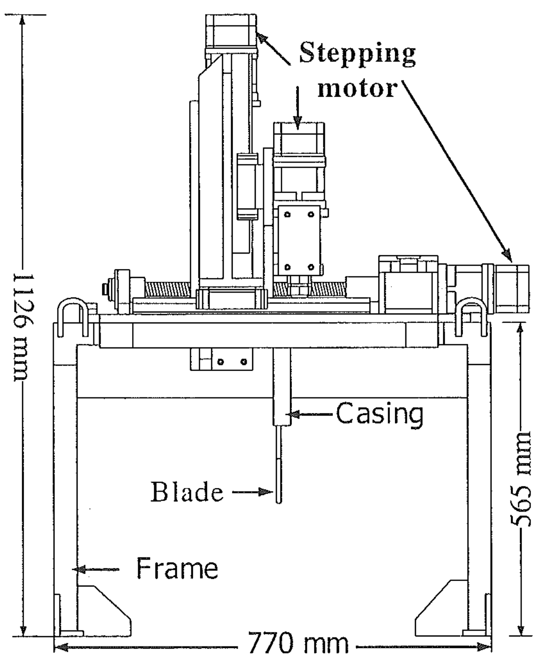

Fig. 9 Fix excavator

Table 2 Specification of the In-Flight Excavator

Size	Excavator	W770 x D545 x H1126 (mm)
	Controller	W500 x D275 x H425 (mm)
Weight	Total	200 (kg)
	Excavator	139 (kg)
	Stand	61 (kg)
Excavation block	Rotation speed	0~35 (rpm) (0.1 step)
	Motor	370 (kgf.cm) Stepping motor with Harmonic reducer max. torque: 36.3 (N.m)
	Speed sensing	Optical sensor
Top-end of excavation block (changeable)	For excavation without sheet pile	W110 x 100(mm) x 2 lines
	With sheet pile	W110 x D100(mm) x 2 lines
	With sheet pile and wall	W110 x D92(mm) x 2 lines
Elevation block	Elevation height	230 (mm)
	Limit sensing	Photo micro sensor
	Speed	0~5 (m/sec) (0.1 step)
	Motor	370 (kgf.cm) Stepping motor with Harmonic reducer max. torque: 36.3 (N.m)
Horizontal motion block	Elevation height	260 (mm)
	Limit sensing	Photo micro sensor
	Speed	0~5 (m/sec) (0.1 step)
	Motor	370 (kgf.cm) Stepping motor with Harmonic reducer max. torque: 36.3 (N.m)
Control and measurement	Control method	Manual and automatic operation by PC
	Program language	C Language
	Measurement	Speed and displacement of excavation

The excavator could dig 10 cm x 20 cm or 10 cm x 10 cm section in one dig with 20 cm depth. All the processes of excavation are controlled by 4 stepping motors. This in-flight excavator can be controlled manually or in semi-automatic way from the operating room. Maximum rotation of the auger is 35 rpm and the ascent and descent speed of the auger is 5 mm/sec and drifting speed is 5 mm/sec. In addition, it is possible to replace the auger by blade which could be moved up, down, left and right in a horizontal direction. This enables the excavation of the soil ground in a horizontal direction making it possible to shift away the excavated material smoothly from the slope.

EXPERIMENTAL CONDITIONS

Model soil ground are prepared under three compaction pressures; 100kPa, 150kPa and 200kPa. During the centrifuge test, two types of excavation procedures are followed depending upon the trench and toe excavating steps. Types and cases of the experiment are shown in Table 3. In the first type (100 kPa, 150 kPa-Case1 and 200 kPa), excavation was at first started from the toe of the slope. At the end, before the failure, trench excavation is made (except for the model ground 100 kPa) from the excavated portion of the slope itself. In the second type (150 kPa-Case2), trench and slope excavations are started from the beginning and followed up to the end (failure). Two types of excavations followed for the model ground compacted at 150 kPa are shown in Fig. 10. Excavation steps are represented by 1, 2, 3, and so on. All the experiments with the excavation are carried out at 50G.

Table 3 Excavation case and step

	Excavation	First Step
100 kPa	Toe	Toe only
150 kPa-Case1	Toe+Trench	Toe
150 kPa-Case2	Toe+Trench	Trench

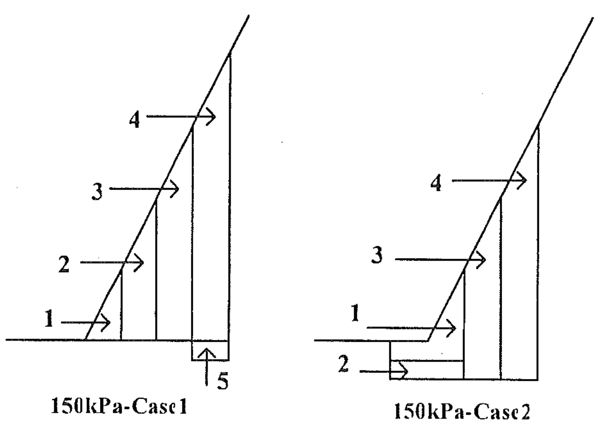

Fig. 10 Excavation Steps

TEST RESULTS AND DISCUSSIONS

The maximum height just before the failure for the all the model tests are shown in Table 4. Comparing the vertical height of the model test just before failure it is observed that there is increase in the vertical height just before failure with the increase in the compaction pressure. Because strength of the model ground increases with the increase in the compaction pressure and this finally increases the vertical height of the slope. But comparing the vertical heights of 150 kPa-Case1 and Case2, the effect of type of excavation at the toe of the slope could be seen. Vertical height for the Case2 is lower than that for the Case1. This implies that if the excavation of the slope at the toe is made without any trench at first, it can give longer vertical height than that for with the trench excavations from the beginning. This might be the resistive force that would be given by the soil layer at the toe. In 150 kPa-Case1, as the toe of the slope is excavated without any trench at the beginning there is reduction in the failure moment to some extent. Resisting force is given by the soil lying below the toe. In 150 kPa-Case2, slope becomes unstable as there is no soil ground at the trench area to reduce such resistive is present as it has no resistive force the bottom. Table 4 also shows the vertical height if the excavation is done in the real ground.

Table 4 Experimental results

Model No.	At the failure time		
	width	height	Height in reality
100 kPa	1.8 cm	2.8 cm	1.4 m
150 kPa-Case1	3.8 cm	8.0 cm	4.0 m
150 kPa-Case2	2.6 cm	6.0 cm	3.0 m
200 kPa	4.7 cm	9.0 cm	4.5 m

Fig. 11 and 12 show the model ground after failure for 150 kPa-Case1 and 150 kPa-Case2. Solid longer broken line shows the original ground (slope) while the dotted line shows the failure plane. Vertical crack is at the top surface and extended up to some depths. This is followed by the circular failure plane.

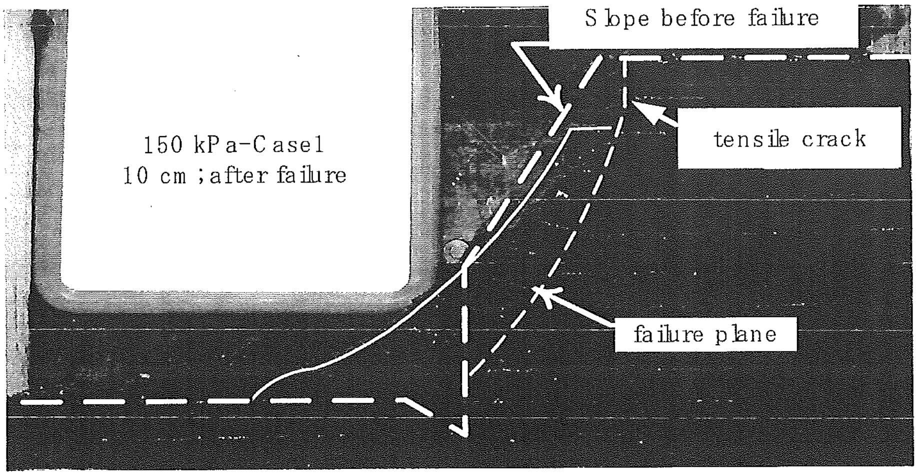

Fig. 11 Model slope after failure for 150 kPa-Case1 (10 cm inward)

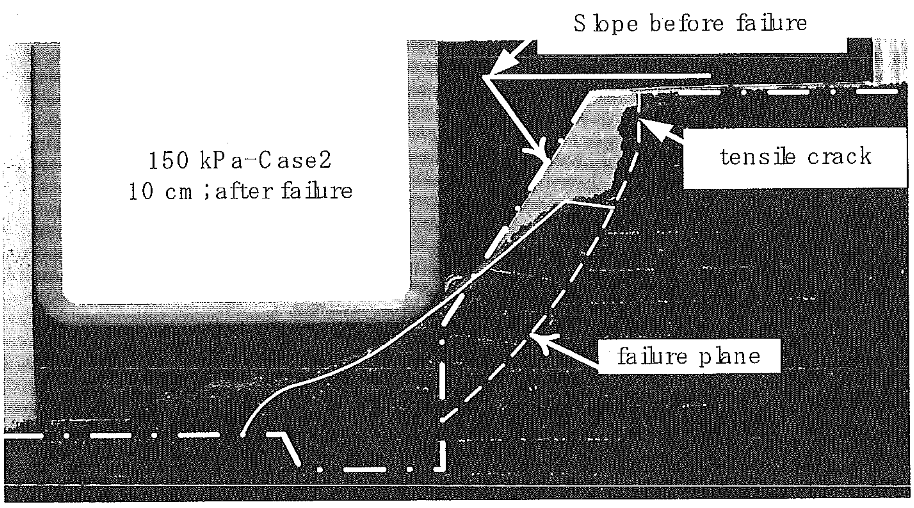

Fig. 12 Model after failure for 150 kPa-Case2 (10 cm inward)

Centrifuge test results for these two cases are shown in Fig. 13 and 14, respectively. In these figures, starting time for each step of excavation time is shown. Comparing the vertical displacements (deformations) on the slope top, it is found that the displacement near the slopes is large and it decreases at the positions farther from the slope. In addition, at each step of excavation, rate of change of deformation values are larger and steeper. In Fig. 15, displacement of the V1 (refer to Fig. 7) displacement gauge just before the failure is shown. According to Saito (1969), in the graph of the elapse time and deformation, one could distinguish 2nd degree creep with constant velocity and 3rd degree creep with faster increment in the displacement with time (acceleration) which will proceed to failure. Similar nature of the displacement-time graph is seen in Fig. 15. This suggests that if some kind of displacement is measured during the excavation, possible failure point could be predicted.

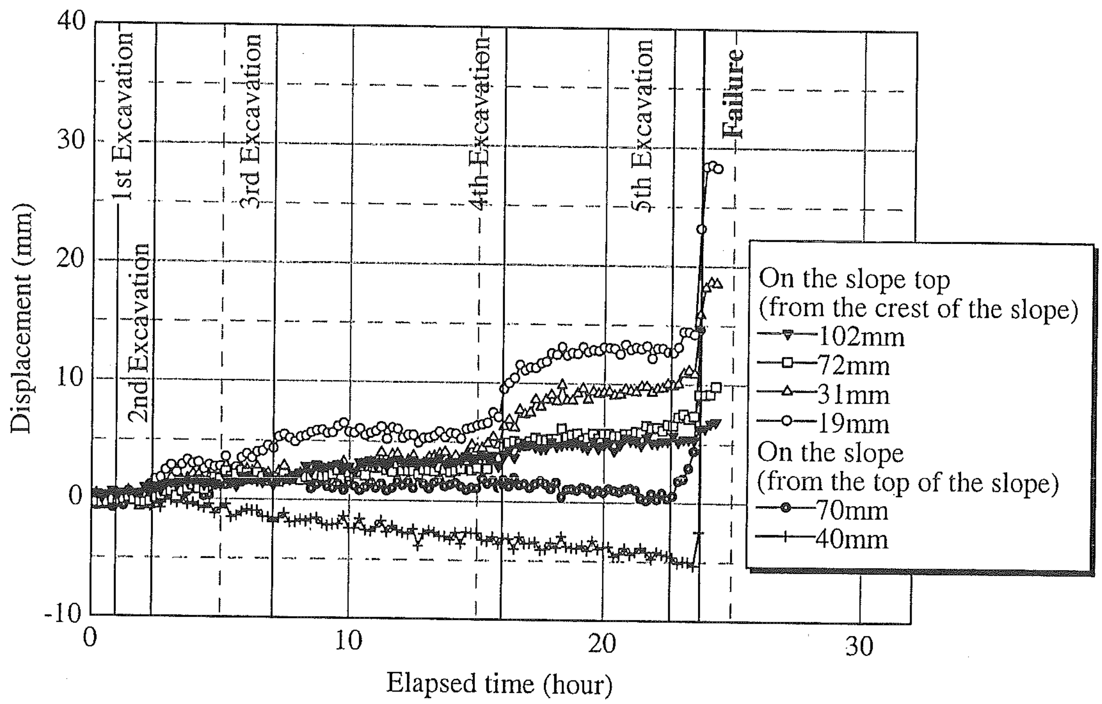

Fig. 13 Displacement vs. elapse time for 150 kPa-Case1 excavation

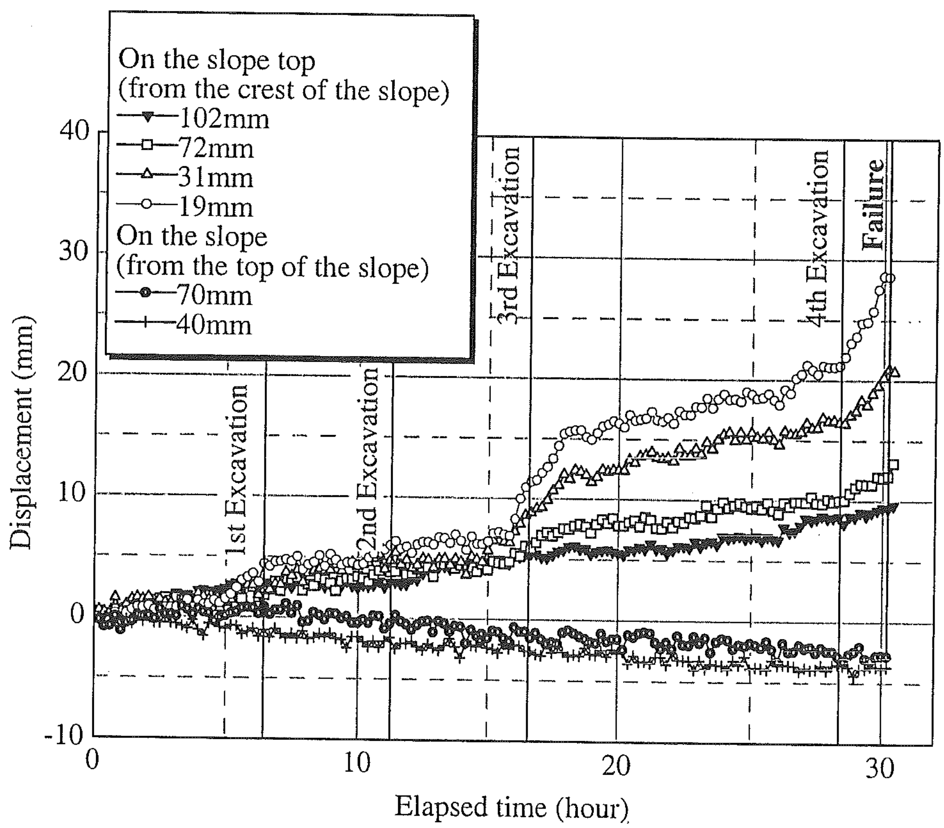

Fig. 14 Displacement vs. elapse time for 150 kPa-Case2 excavation

Fig. 16 shows the displacement of displacement gauge positions from the crest of the slope for 150 kPa-Case1 and 150 kPa-Case2. Displacements are calculated just after each step of excavation after averaging. From the graph, it could be said that with each step of excavation, the crest of slope deformed downward and outward of the slope. But with each step of excavation, displacements measured on the slope move upward. This implies that with each step of excavation, the volume of the soil on the crest move downward and outward from the slope. Keeping this in mind and looking at Fig. 8 and 11, it could be stated that circular failure had occurred. Vertical crack could also be seen in these photographs although they are smaller in depth.

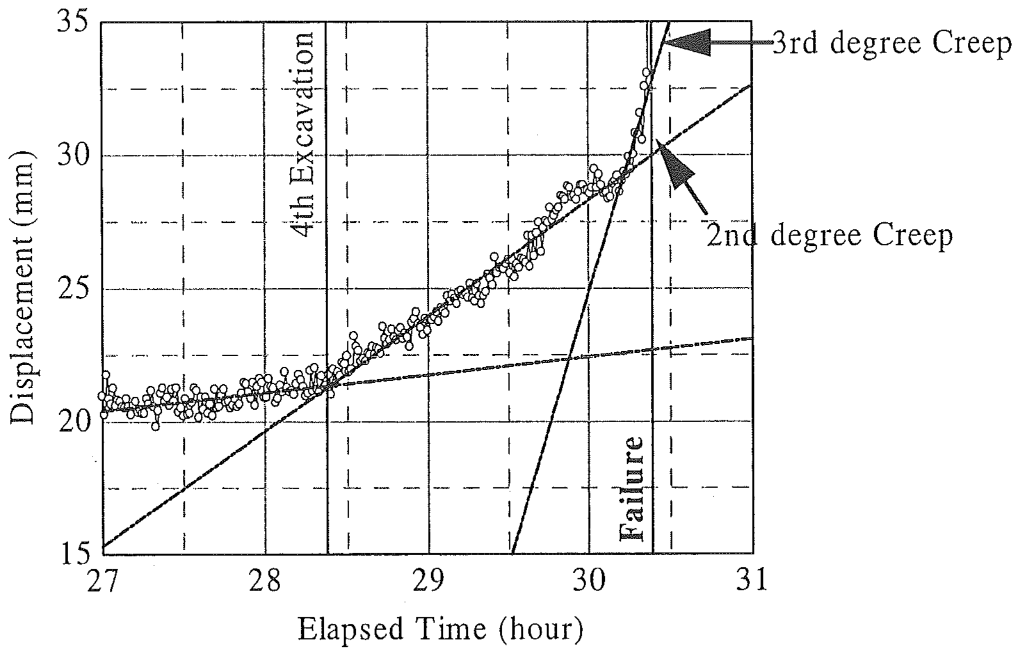

Fig. 15 Displacent vs. elapsed time graph for 150 kPa-Case2

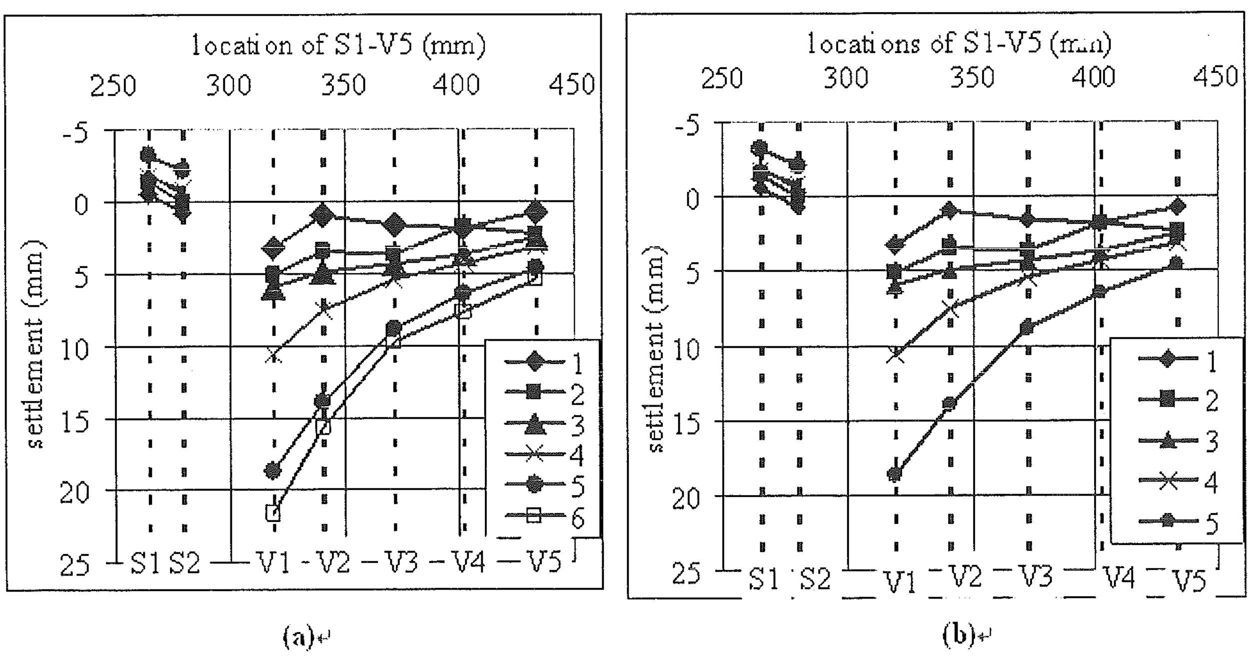

Fig. 16 Displacement and position of displacement gauges (a) 150 kPa-Case 1 and (b) 150 kPa-Case2

CONCLUSIONS

From the centrifuge test results the following conclusions are made:

1. Vertical height of the slope just before failure increased with the increment in the compaction pressure.
2. Vertical height before the failure is larger for the excavation made without trench than the one done with the trench excavation at the start of excavation.
3. Displacement-time graph obtained from the test can be clearly distinguished into the 2nd degree and 3rd degree creep, which might be helpful in predicting possible slope failure time.
4. As seen in most of the slope failure, tensile crack is developed on the top surface which is followed by the circular slope failure.

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MEASUREMENT OF SLOPE MOVEMENT DURING THE SLOPE EXCAVATION OF SMALL SIZE FULL SCALE MODEL

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ABSTRACT

The main purpose of the research described in this paper is to develop an instrument, which could measure the slope movement either directly or indirectly in the real excavating field with which the pattern of failure could be predicted in advance. In this study, slope excavation is carried out using a small size full scale test model made up of river sand. A new instrument, which is a kind of acceleration sensor, called hereby a Tilt-sensor, is used along with laser sensors and linear variable differential transducer (LVDT) to measure the movement of the slopes and top surface of the slope (crest). Changes in the slope angle measured by this new tilt-sensor and the deformations measured by laser sensors and LVDTs on the slope and top surface of the slope (crest) due to tne excavation of trench and toe of the slopes showed similar trend. Therefore, applicability of tilt-sensor could be used in the field where real excavation is carried out.

KEYWORDS: Slope movement, Tilt-sensor, Slope excavation.

INTRODUCTION

There are many accidents in which workers are injured or dead due to the sudden slope failure in the excavation sites. In almost all of such accidents, only stability of the slopes is considered for the final (completed) slopes and safety analysis is carried out for the final step. Stability analysis is generally not carried out and thought during the middle stages of excavations. In such situation, even if some unstable sites are found, which may slide (fail) immediately, it might not be possible to repair them instantly. Although complete protection of such slope failure is not possible, it might be possible to prevent the damage due to slope failure to minimum by using fences or cover-ups, which might decrease the speed of the failure or reduce the amount and flow of soil debris. But it is not good enough to depend upon such protection measures, which have limitations in its protection. It is difficult to prevent the failure or collapse completely and perfectly. However, it would be good if one could predict the time of collapse in advance during the excavation which might decrease the damage.

Measurement of the displacement and deformations of ground surfaces are generally carried out at the construction sites such as embankments and reclamation sites. Doing such measurements, one can know the amount of settlement and the flow direction, which facilitates

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the construction management to go smoothly and a good maintenance even after the completion of the construction works. In the past and recently, many researches have presented various methods of measuring the movement of the slope. Japanese Geotechnical Society has given four standard methods for the measurement of the settlement and movement of the slope. Accordingly, in those methods following things are mainly used: 1) settlement plate (JGS 1712-2003), 2) displacement wedges (JGS 1711-2003), 3) portable extensometers (JGS 1725-2003) and 4) water levelling tube which measures the angle (JGS 1721-2003). Among these, the first two methods are applicable to construction works such as embankment above the soft ground. The latter two methods are generally used to measure the movement of the landslide. However, all of these methods require some fixed points. In addition, they are time consuming and difficult to set up in the actual field where slope excavation is going on. In the excavating field where the continuous observation is needed to inform the workers about the current status and to make them escape before the quick failure, the above mentioned methods are not proper. Many new methods have been introduced using Optical Fiber Sensors, Non-Prism Total Station, 3-D Laser Scanner, Optical Fiber Extensometer, Fiber Bragg Grating (FBG), Brillouin Optical Time Domain Reflector (B-OTDR) etc. All of these are difficult to set up, handle and maintain the sensitivity. In addition, these new methods are too expensive.

In this research, with the aim of predicting the movement of slope in some kind of shape in advance, measurement of slope movement during the excavation and just before the slope failure was made by using a new tilt-sensor which measures the slope-angle along with laser sensors and LVDTs. Authors have utilised this type of sensor for the first time in research. Tilt-sensor is in fact a kind of acceleration measuring sensor which is use in the motor vehicles. Here, applicability of this tilt-sensor is checked using a small size full-scale test model inside the laboratory so that it could be used in the field. The slopes became unstable by excavating the trenches at the toes of the slope. Excavations were continued until the slopes came to complete failure. Finally, comparison of movements (both deformations and angle) of the slope and top surface of the slope measured by the laser sensors, LVDTs and tilt-sensors was made from the beginning to the end until the slope failed. Similar trend for deformation and change in the slope angles with the time was found.

SMALL SIZE FULL SCALE TEST

Full scale test box

In order to carry to out the small size full scale test in the laboratory, a full scale test box was made. Framework of the test box is constructed from the wooden planks, which are supported externally by the iron plates/beams. The whole framework is divided into two sections: lower (1.35 mx 2.7 m x 1.3 m) and upper (1.35 m x 1.2 x 0.88 m) which facilitate to make different types of slopes with different conditions. Test box could be assembled either with lower section (Fig. 1) only or with the combination of lower and upper sections (Fig. 2). If the slope height is lower or equal to 1.3 m, then the lower section is sufficient to make the test. In the case where the required slope height is larger than 1.3 m, upper section is allowed to attach to the lower section. Since the frontal section of this combined structure is 1.3 m, the test with slope height smaller than equal to 1.3 m is also possible. In this case, load of the material in the backside should be considered as the surcharge. Here, model test slope with lower section only is named as "One-step, Short" (Fig. 3). Model test slopes using the combined structures are divided into two groups. If the model test slope uses only the frontal part, then it is termed as "Two-step, Short" (Fig. 4). Similarly, the model test slope using both the upper and lower sections is termed as "Two-step, Long" (Fig. 5). In this research, these three types of model tests are performed.

EXPERIMENTAL CONDITIONS

Full scale test model

River sand was used as the test material. Here, medium dense test model was tried to obtain. Manually compaction was done in layers by tamping the spread sand by foot and small wooden planks. In order to reduce the friction between the inner walls of the test box and sand, inner surfaces were made smoother. Once the compaction was over, wooden planks of the front, as well side faces were removed as per requirement and cutting of slopes were done so that the test model of desired slope angle could be obtained. Here, three types of model tests: "One-Step, Short" (Slope-I-3), "Two-Step, Short" (Slope-V-1) and "Two-Step, Long" (Slope-V-2) were done. Water content, density and slope angle for each test are shown in Table 1. As shown in Figs. 1, 2 and 3, 0.3 m thick base was left at the beginning when the model slopes were made so that trench excavation could be made.

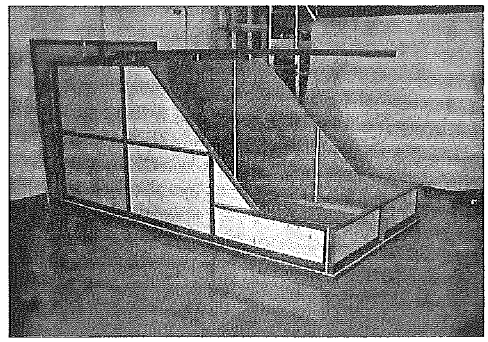

Fig. 1 Model box with lower section

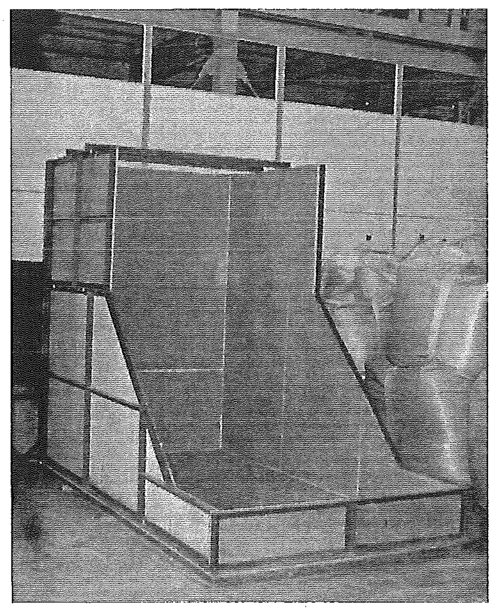

Fig. 2 Model box with lower and upper sections attached

As shown in Fig. 6, excavation was done in steps. In Fig. 6, steps are shown by numbers. Number of steps varied with the test as the excavation was tried to make until the slope comes to complete failure. This might be due to the difference in the test conditions including slope angle shown in Table 1. Here, step represents either trench or toe excavations. Trench means the excavation made in front of the toe of the slope and below the ground level. Toe excavation represents the excavation made at the lower section of the slope (toe) and above the ground level. In all the tests, at first, the trench excavation was done. Depth and width of each trench as well as the toe excavation were different. Also, trench after trench and toe after toe might also be possible. Between each step of excavations, about 5 minutes interval was allowed so that the movement of slopes as well as the top surface of the slope could be observed. In case of Slope-I-3, trench of 15 cm width and 15 cm depth was made at first. Then excavation of toe was done. Slope was failed during the excavation of toe (second step). Quicker failure might be due to low density of the model test (loose compaction).