Geotehničko inženjerstvo, 2012-2013.

SANACIJA KLIZIŠTA

- Nastanak klizanja
- Mehanizmi klizanja
- Analiza klizišta
- Mjere sanacije

MEHANIZMI KLIZANJA:

- ZONE KLIZANJA
- KLIZNA PLOHA

OBILJEŽJA KLIZIŠTA:

- PUKOTINE U TLU
- NABORI
- NAGNUTI ZIDOVI
- PUKOTINE U ZGRADAMA - VERTIKALNA I HORIZONTALNA POMICANJA
- OVLAŽENE ZONE PO POKOSU (VODA)
- POJAVA VODE U NOŽICI
- SAVIJENA STABLA
- PUKOTINE U ASFALTU CESTA, SAVIJENE OD SREDINE PREMA RUBU

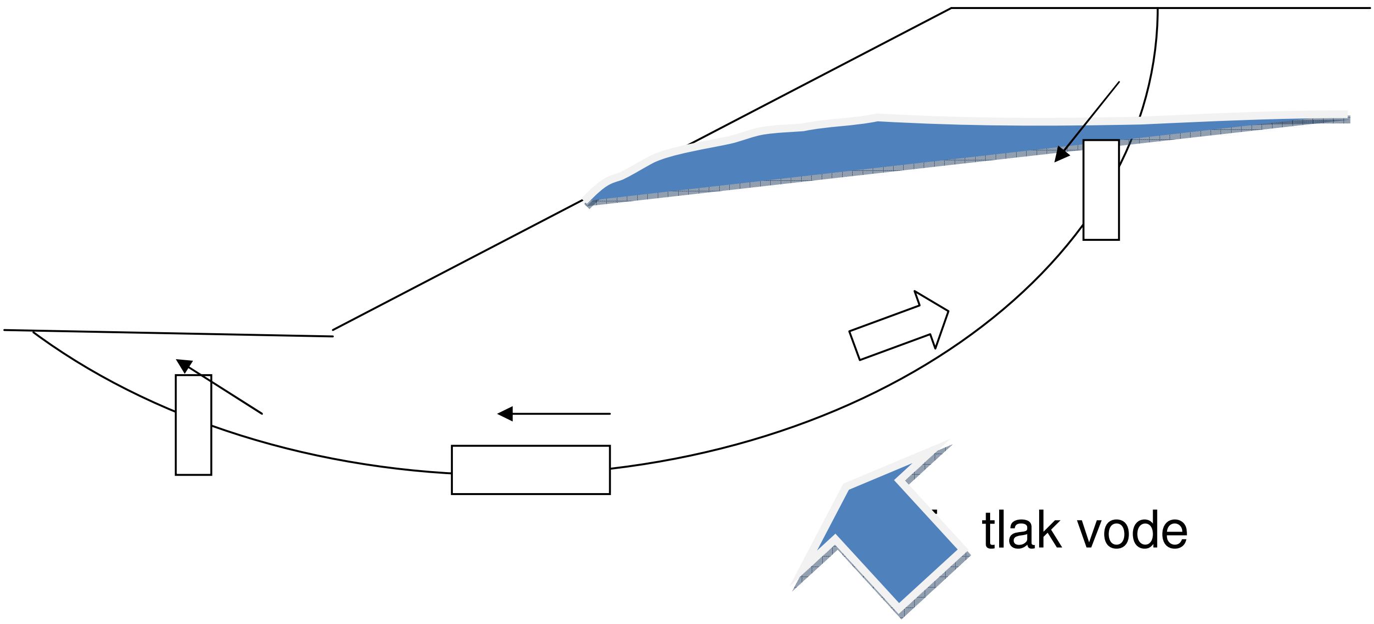
KLIZIŠTE NASTALO RADI LOŠE IZVEDBE POKOSA MEĐU ZGRADAMA

ZAŠTO NASTAJE KLIZANJE ?

$$\tau = c + \sigma' n \tan \varphi$$

Kada posmična naprezanja prekorače čvrstoću :

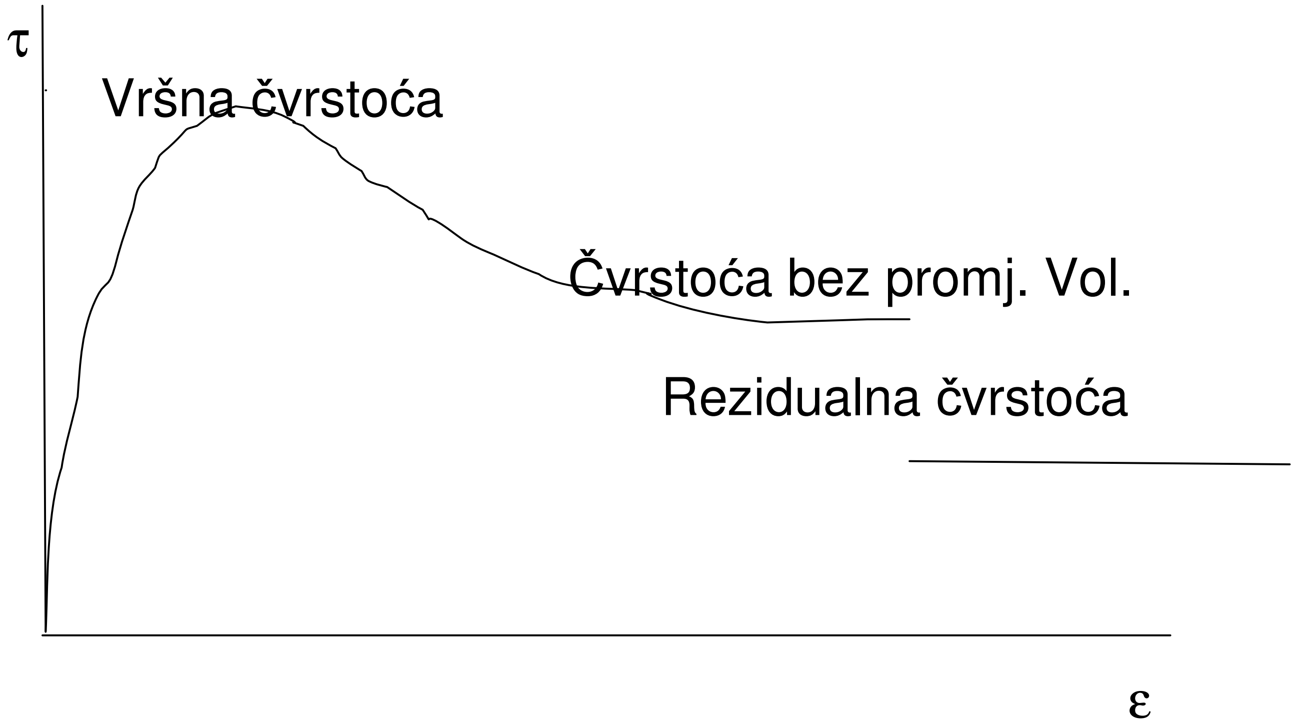
- Veliki porni tlak – padaju vertikalna efektivna naprezanja
- Promjena posmične otpornosti sa deformacijom (manji kut trenja)
- Djelovanje podzemne vode
- Djelovanje potresa



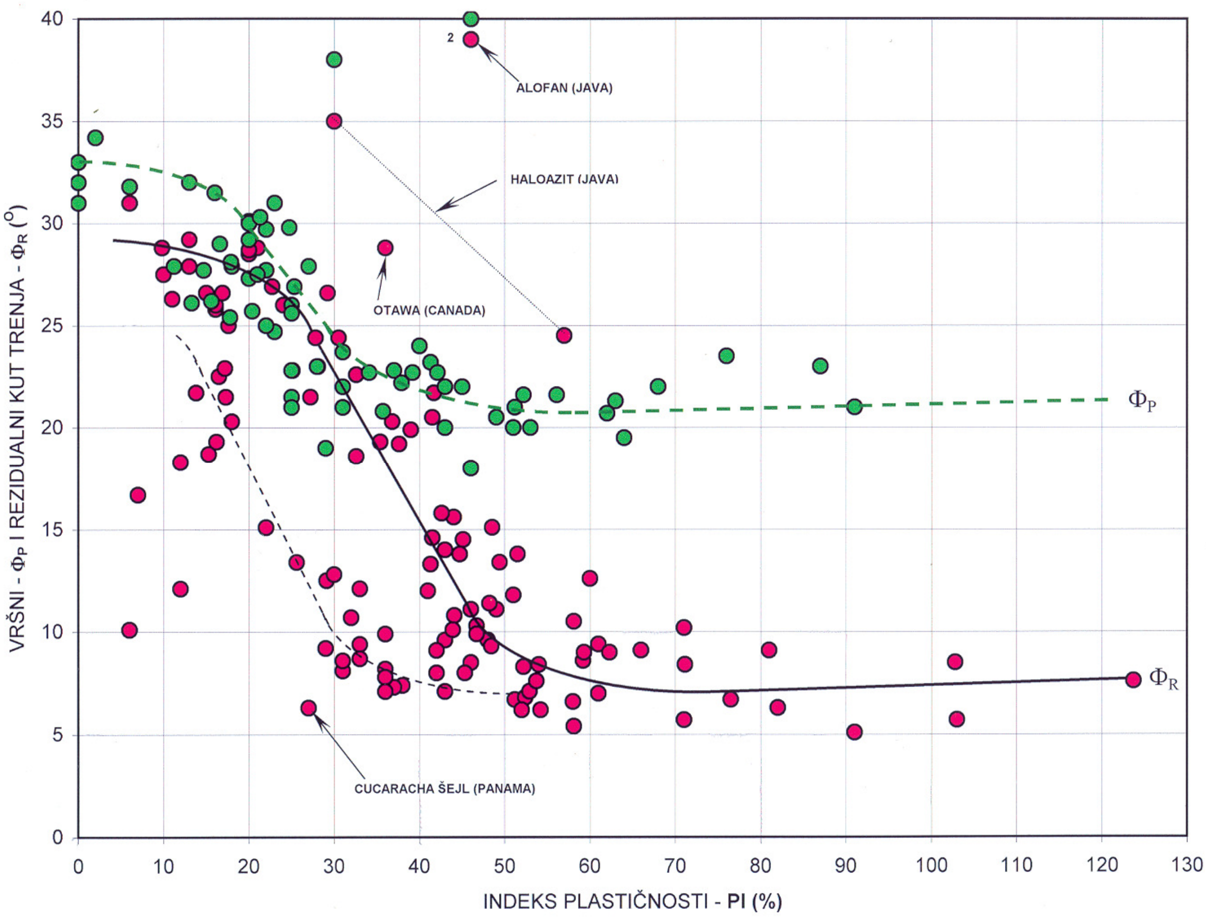
Način sloma tla :

- Vlak – izravni posmik - tlak

Ponašanje tla u posmiku:



- Troosni posmik
- Rezidualna čvrstoća – kružni posmik
- Uloga plastičnosti tla



Veća plastičnost tla umanjuje kut unutarnjeg trenja – i vršnu i rezidualnu vrijednost

ANALIZA STABILNOSTI

1. faza

AEROFOTOSNIMCI , PREGLED TERENA, PREGLED OBJEKATA, OPĆA GEOLOŠKA KARTA

2. faza

1. ISTRAŽNI RADOVI NA TERENU
   – BUŠENJA, - BROJ, DUBINA (MIN 5 M ISPOD KLIZNE ZONE) - - UZORKOVANJA, - NEPOREMEĆEI UZORCI
   PIEZOMETRI – MJERENJE NIVOA VODE
   MJERENJA – POMACI TLA I OBJEKATA

2. LABORATORIJSKA ISPITIVANJA – KLASIF. + POSMIK
   PAŽLJIV ODABIR UZORAKA I PARAMETARA TLA

3. faza

3. MODEL KLIZANJA – RASPORED SLOJEVA, UTJECAJ VODE

Model i oponašanje prirodnih uvjeta – PRESUDNO

(višestruke klizne plohe, plitke i duboke, provjeravaju se na modelu koji se zove geotehnički model klizanja a koji je nastao kopilacijom svih podataka –geoloških, geotehničkih i hidrogeoloških).

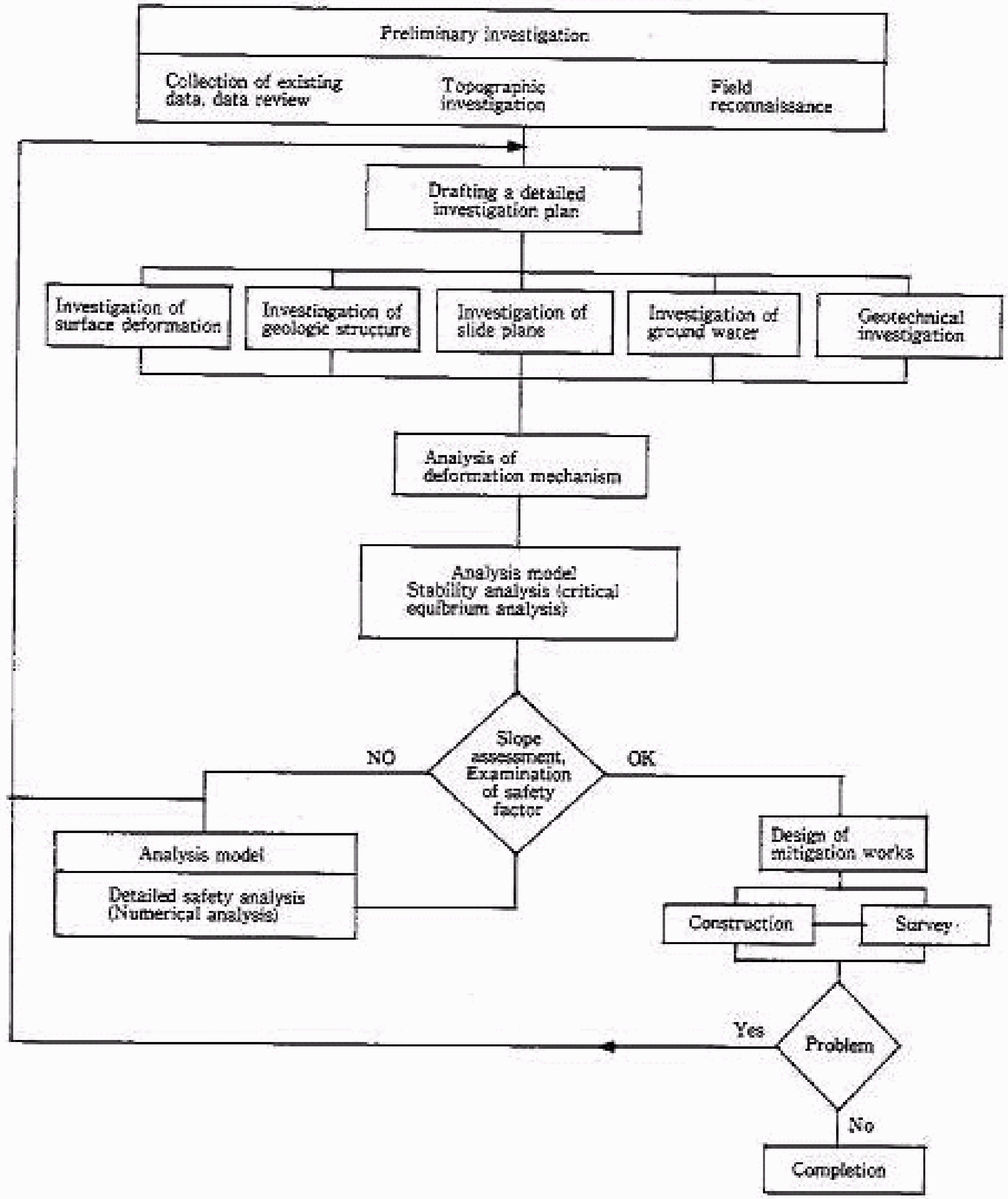
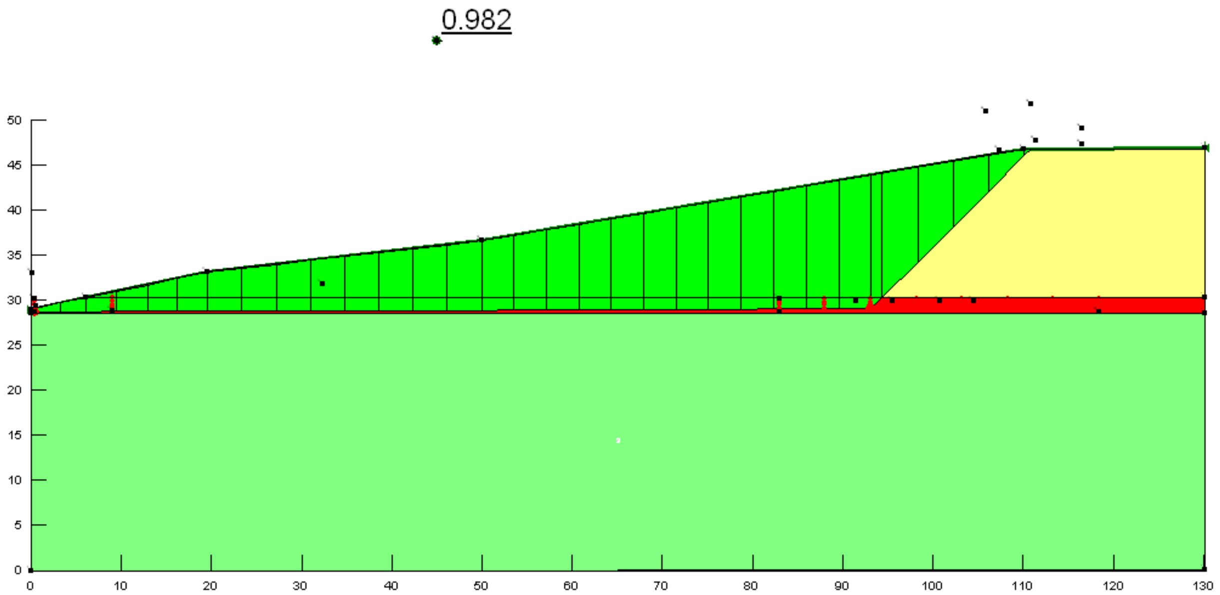


Fig. 10 Flow chart for landslide investigation and analysis

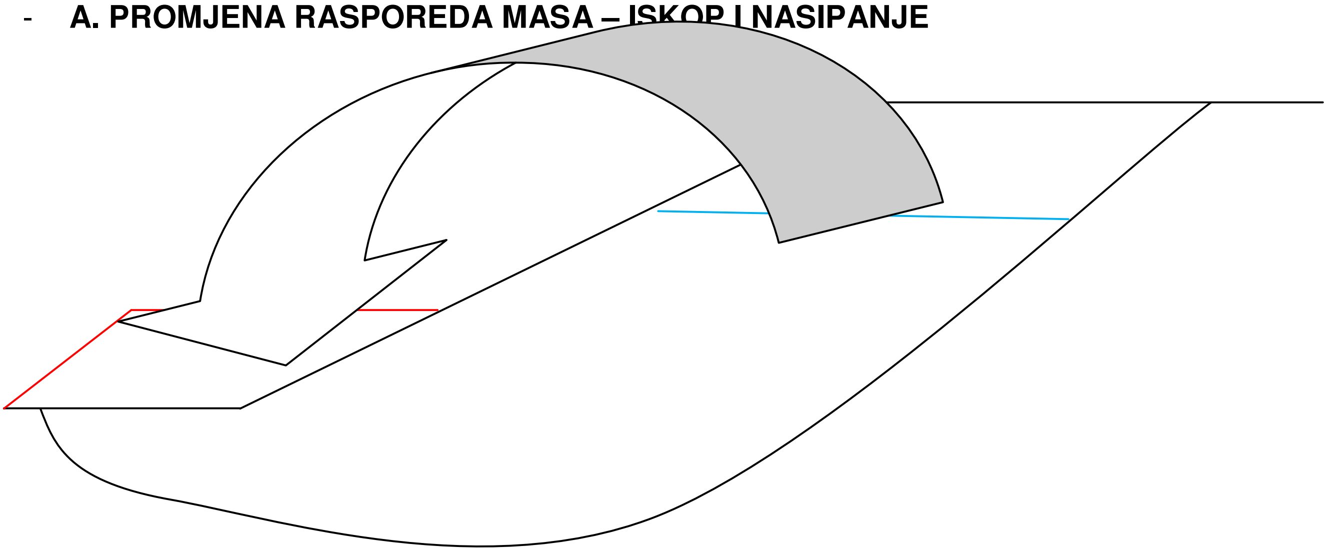
Plan i program postupaka analize klizišta, prema Japanskom pravilniku

JEDNOSTAVAN MODEL – ZAJČEVA ZAGREB – klizanje usljed glinenog proslojka, staro klizište – rezidualni parametar kut unutarnjeg trenja



MJERE SANACIJE.

- **A. PROMJENA RASPOREDA MASA – ISKOP I NASIPANJE**



- Efekti:

  SMANJENJE TEŽINE KLIZNOG TIJELA I RASTEREĆENJE POSMIČNOG NAPREZANJA U GORNJEM DIJELU KL. TIJELA

POVEĆANJE VERTIKALNOG NAPREZANJA U NOŽICI KOSINE ČIME SE POVEĆAVAJU POSMIČNA NAPREZANJA NA KL. PLOHI

KORISTI SE MATERIJAL KOJI POSTOJI

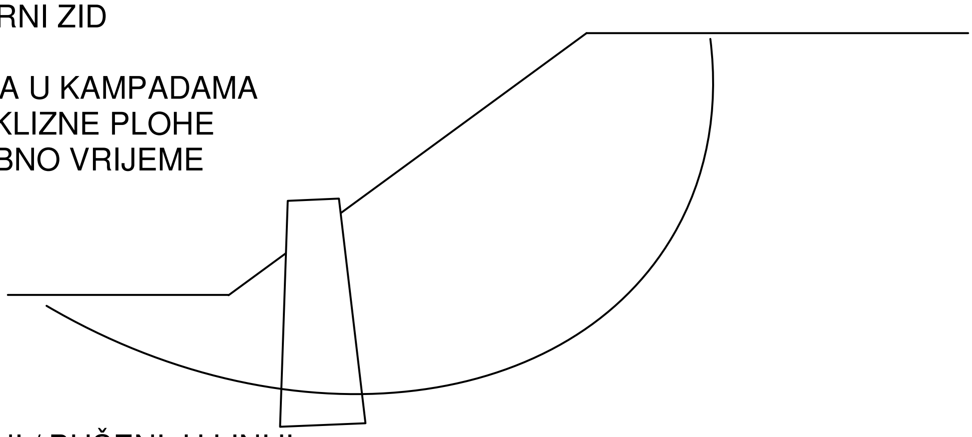
NEDOSTATAK: ČESTO JE TEŠKO IZVESTI, ČESTO NEDOVOLJAN EFEKT

- **B. POTPORNE KONSTRUKCIJE – PILOTI, ZIDOVI**

PREUZETI SILE KLIZANJA POTPORNOM KONSTRUKCIJOM

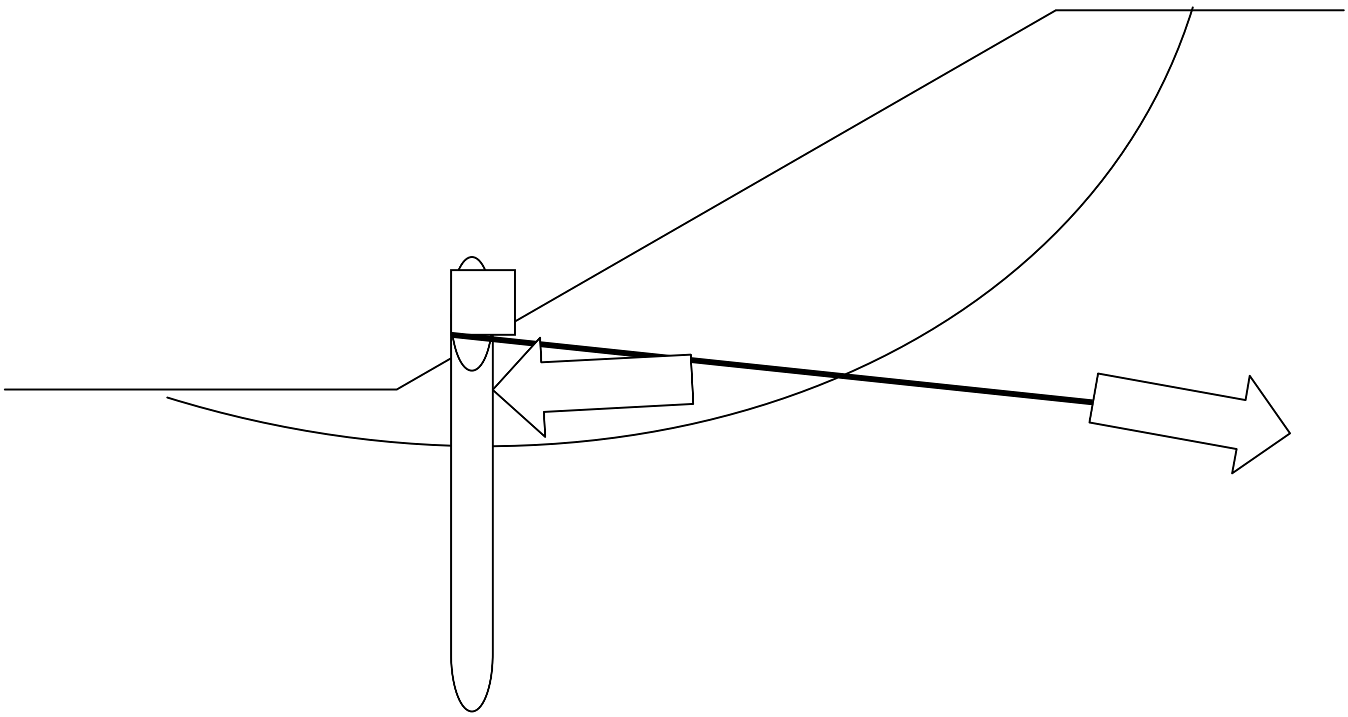
- POTPORNI ZID

- IZVEDBA U KAMPADAMA
- ISPOD KLIZNE PLOHE
- POTREBNO VRIJEME



- PILOTI

- ZABIJENI / BUŠENI, U LINIJI
- POVEZANI NAGLAVNOM GREDOM
- ĆESTO SIDRENI
- POSEBAN PRORAČUN NA HORIZONTALNU SILU – ODREZ, SAVIJANJE
- ČESTO SIDRENA KONSTRUKCIJA



- **C. PROMJENA STRUJANJA – DRENOVI**

- PROMJENA STRUJANJA DONOSI SMANJENJE PORNIH TLAKOVA

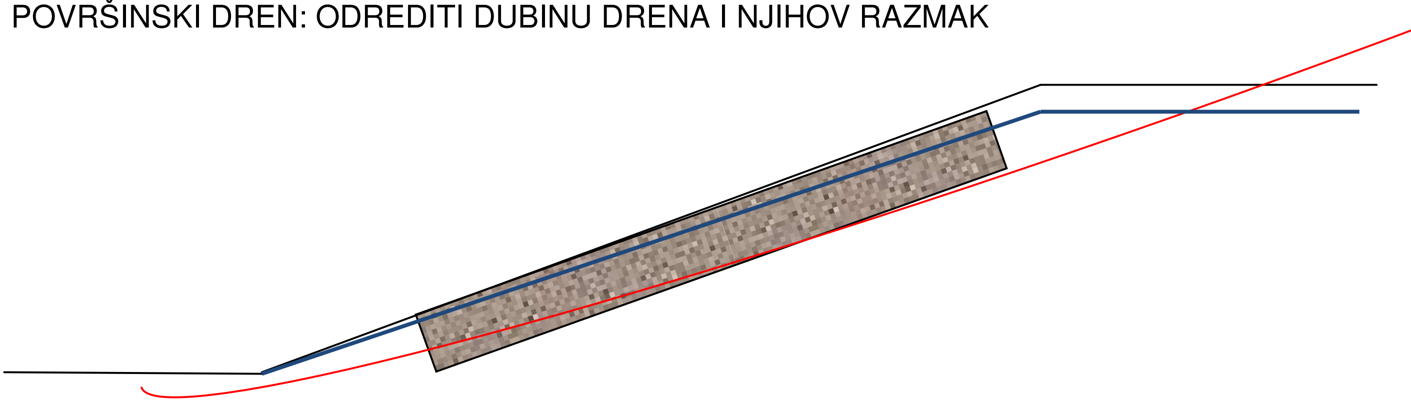
- SMANJENJE PORNIH TLAKOVA IZAZIVA POVEĆANJE EFEKTIVNIH NAPREZANJA, A TIME I POVEĆANJE POSMIČNE ČVRSTOĆE

- ZA PROMJENU PORNIH TLAKOVA POTREBNO JE IZAZVATI PROMJENU STRUJANJA, ŠTO ZAHTIJEVA VRIJEME, PRI ČEMU SE UZ POVEĆANJE EFEKT. NAPREZANJA POJAVLJUJE I DODATNA KONSOLIDACIJA

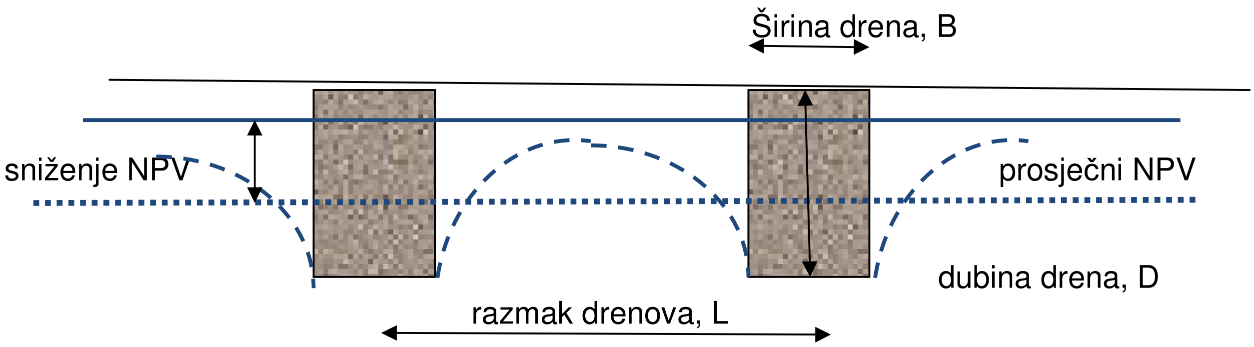
DVA SUSTAVA DRENIRANJA:

1. POVRŠINSKI DRENOVI – ZA PLITKA KLIZANJA, POVRŠINSKA
2. BUŠENI DRENOVI (U DUBINI TLA) – ZA DUBINSKA KLIZANJA

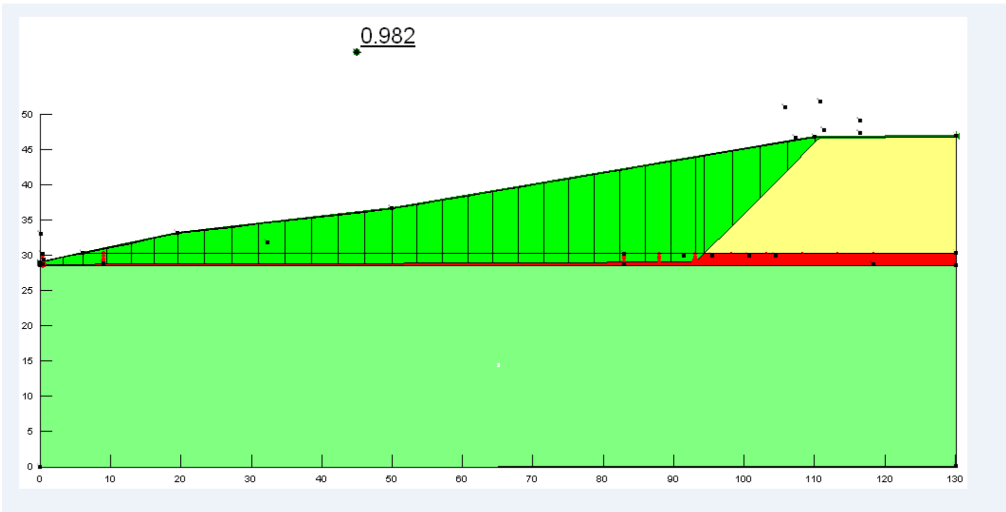
POVRŠINSKI DREN: ODREDITI DUBINU DRENA I NJIHOV RAZMAK



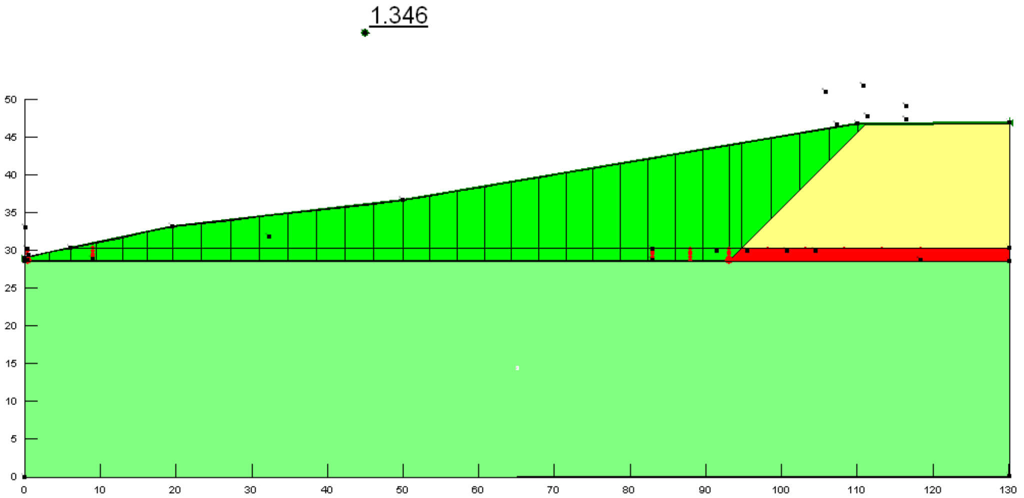
POPREČNI PRESJEK KROZ DREN



- KOPANI POVRŠINSKI KANALI
- ODVODNJA CIJEVIMA
- FILTERSKO PRAVILO
- SKUPLJANJE U ŠAHT – KANALIZACIJA OBORINSKE VODE



Prirodno stanje – voda visoko

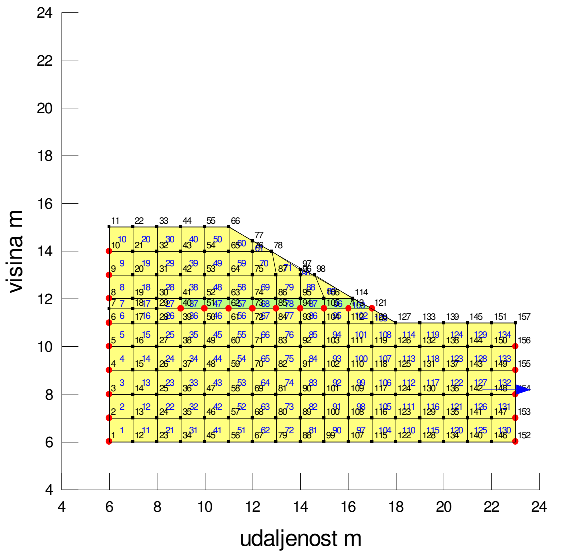


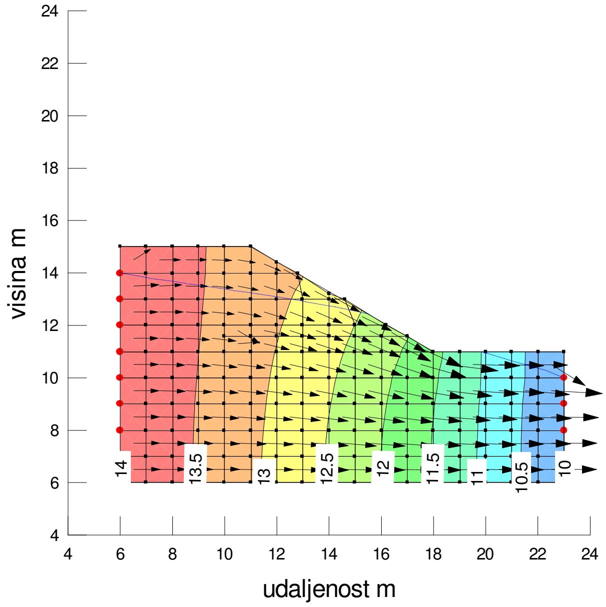
Stanje nakon djelotvornog sniženja vode, za ru=0,2, tj, sniženje vode na 40% udaljenosti gline od površine terena

BUŠENI DRENOVI

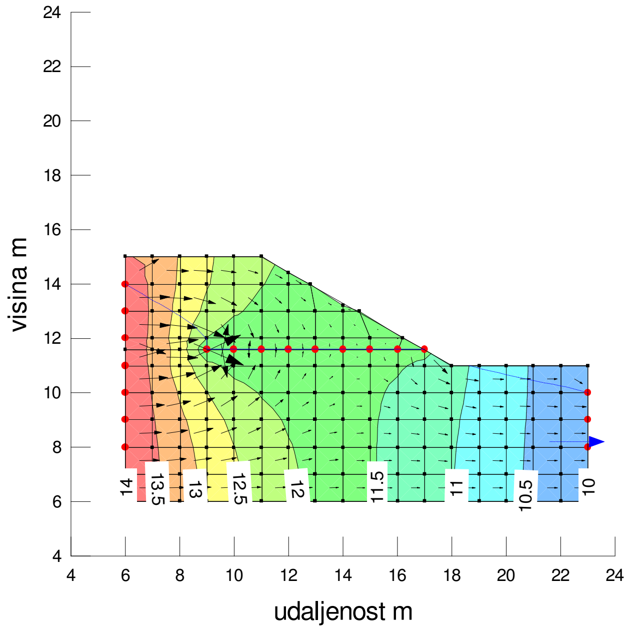
- HORIZONTALNE, BLAGO NAGNUTE BUŠOTINE
- DULJINA (L) OVISI O RAZMAKU DRENOVA (S), ŽELJENOM FAKTORU SIGURNOSTI I VISINI KOSINE
- PRORAČUN POMOĆU PRIPREMLJENIH DIJAGRAMA ILI PROSTORNOG PROCJEĐIVANJA

DVA REDA BUŠENIH DRENOVA, PO 25 M





visina m
udaljenost m
14
13.5
13
12.5
12
11.5
11
10.5
10



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udaljenost m
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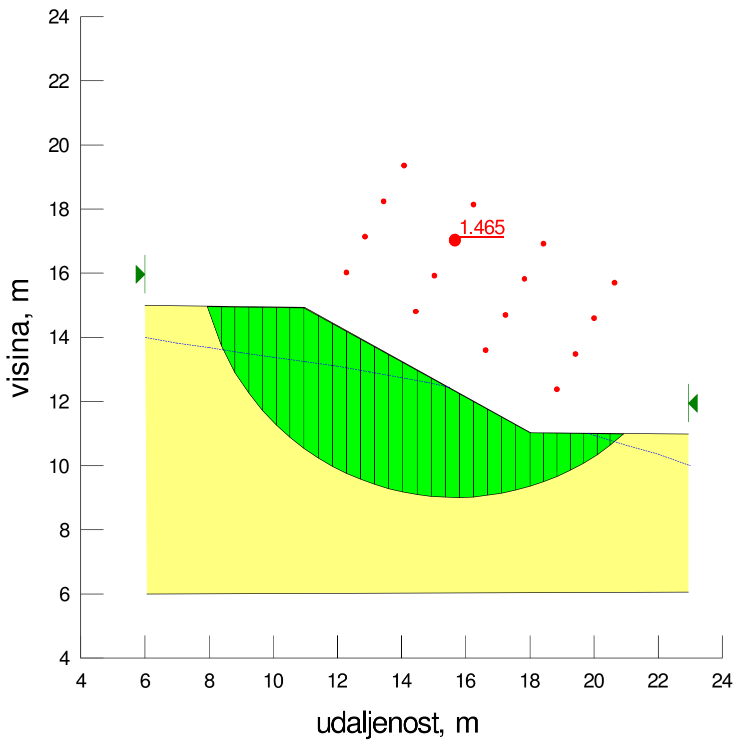

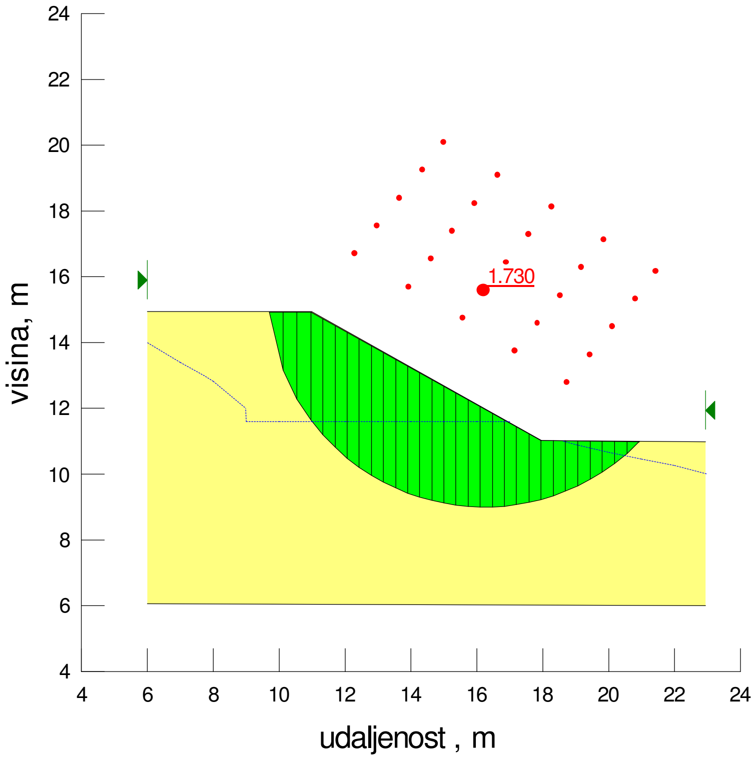

DOVOLJNA PORAST FAKTORA SIGURNOSTI : 20% (Fs ≥ 1,2 – 1,25)

3. Landslide Investigation and Prediction

The flow chart shown in Fig.10 describes the general investigation procedures in an attempt to understand the mechanism of origination of disasters associated with slope movement and to predict the resulting deformation. Investigation items and investigation methods are shown on Table 1.

3.1 Preliminary Investigation

(1) Collection of Existing Data, Data Review
Landslides often occur at specific locations under certain topographic and geologic conditions. Therefore it is important to utilize existing data (history of the problem, records of restoration work, and data review) in order to understand the topography, geology, and properties of similar landslides. It is also important to understand their relationship with meteorologic factors, period of activity, existence of any warning sign, ground water conditions, chronology of topographic change or erosion by rivers, earthquakes, and other factors which may have a relationship with the slope deformation surrounding the investigation site area prior to the detailed investigation.
(2) Topographic Investigation
It is necessary to identify any changes in the site topography. That can be accomplished by recognizing; 1) the overall topographic feature of the site; 2) understanding the topographic characteristics of the site slopes; and 3) estimating the regional geologic structure of the site. Such methods include comparing the aerial photographs of the site and vicinity taken prior to and after the sliding, and interpreting the topographic maps and aerial photographs.

In Japan, aerial photographs are taken every few years over the entire country at a scale between 1/10000 to 1/40000. These photographs are used to understand the chronologic and topographic changes over the country. Furthermore, in order to be able to effectively interpret the phenomena related to microtopography and landslides, large scale aerial photographs with a scale of 1/8000 to 1/15000 are often taken. By utilizing aerial photographs, it is possible to interpret landslide phenomena and warning signs, geology and geologic structure, topography and distribution of vegetation type. For landslide investigations, it is useful to identify and interpret the distribution and continuity of knick lines, gentle slopes, gullies and cracks in the photos to aid in preparing a photo interpretation map. The map can then be utilized during the field investigation.

The recent popularity of remote sensing using satellite photographs has been particularly useful for analysis utilizing the thermal infrared spectrum which is possible to estimate the distribution of slide areas and ground water, and live vegetation. Remote sensing can be used for analysis of topographic characteristics and topographic in terrain susceptible to landsliding.

(3) Field Investigation
With an approximate understanding of the overall topographic feature and knowledge of the distinction(s) of movement and aerial extent of the sliding block(s) (viewed from the

opposite side), a detailed field investigation plan can be developed to delineate the aerial extent and a general direction of movement of the landslide zone, assess the geology and geologic structure, estimate the cause(s) of the sliding, and predict future movement. The field investigation should not include just the actual landslide area, but also exists. The field investigation should also include areas where aerial photographic interpretation is difficult or unclear, and in areas that could aid in the understanding of particular topographic features and characteristics.

3.2 Drafting a Detailed Investigation Plan

In order to examine the follow item, a detailed investigation which will satisfy the objectives under the listings in the investigation methods and observation instruments in the Table 1, should be planned.

- (1) aerial extent of the slide, differentiation of moving blocks and identification of the direction of movement
- (2) location and shape of slide plane(s)
- (3) nature of landslide block(s)
- (4) possibility of further or future movement on slopes above the existing slide
- (5) possibility of further, future or accelerated sliding
- (6) distribution of ground water

Survey lines can be established on each moving block on the ground where the slide mass is expected to be thickest and where the stability analysis and plan for control works will be emphasized. As a general rule, the main survey line should be placed where the width of the slide exceeds 100m with subsidiary survey lines established at approximately 50m intervals (Fig.11).
Exploratory borings should be drilled on the order of every 30-40m. At least three borings should be drilled along the main survey line with one boring drilled at least 5 t0 10 m below the slide plane. During the early stage of the investigation, it is particularly important to have an accurate estimate of the configuration and location of the slide plane(s) an adequate boring depth can be achieved (Fig.12).
Seismic survey lines should be placed at intervals between 50-100m, and electric survey and radioactivity survey lines should be placed at 20-50m intervals. A survey should be conducted along the main survey line as well as along the longitudinal survey lines that cross the main survey line and subsidiary survey lines. For the seismic survey, the survey points should be established at 5-10m intervals, 20-50m interval for the electric survey, and at 3-5m intervals for the radioactivity survey. Furthermore, to verify the results of the geophysical surveys it is important to drill borings at the survey line intersections.

3.3 Detailed Investigation

(1) Investigation of Surface Deformation
The investigation of surface deformation is conducted to define the boundaries of the landslide, size, level of activity and direction(s) of the movement, and to determine

individual moving blocks of the main slide. The presence of scarps and transverse cracks are useful for determining whether the potential for future activity exists.

Instrumentation used for the surface deformation investigation includes extensometers, ground tiltmeters, movement determination by survey methods including transverse survey, grid survey, laser survey from the opposite bank, movement determination by aerial photographs, and G.P.S.(Fig.13) provides an example of instrumentation.

- **1) Extensometer** The extensometer is used to measure relative movement by comparing the extension of two points. The extensometers are generally installed across the main scarp, at transverse crack and transverse ridges near the toe or front portion of the slide and parallel to the suspected slide movement (Fig.14). By arranging a series of interconnecting extensometers from the main scarp to the toe of a complex landslide that has many moving slide blocks, the resulting data could aid in clearly delineating the individual slide blocks. Measurements should be accurate to within 0.2mm, and the magnitude of the movement and daily rainfall data should be included to establish the relationship between the measurable movement and the precipitation rate (Fig.15).
- **2)Tiltmeter** The ground tiltmeter is useful for determining the deformation at the head and toe portions and sometimes along the flanks of the landslide, or to assess the possibility of future deformation. A level type tiltmeter is most conventional. The tiltmeter is capable of measuring the N-S and E-W components (Fig.16) The magnitude of tilting and tilt directions can be determined directly from the instrument panel. Furthermore, in order to determine the characteristics of the deformation, the results are shown chronologically along with the daily rainfall totals. The relationship between the magnitude of tilting and the cumulative effect of tilting, rainfall totals and groundwater levels are shown on Fig.17.

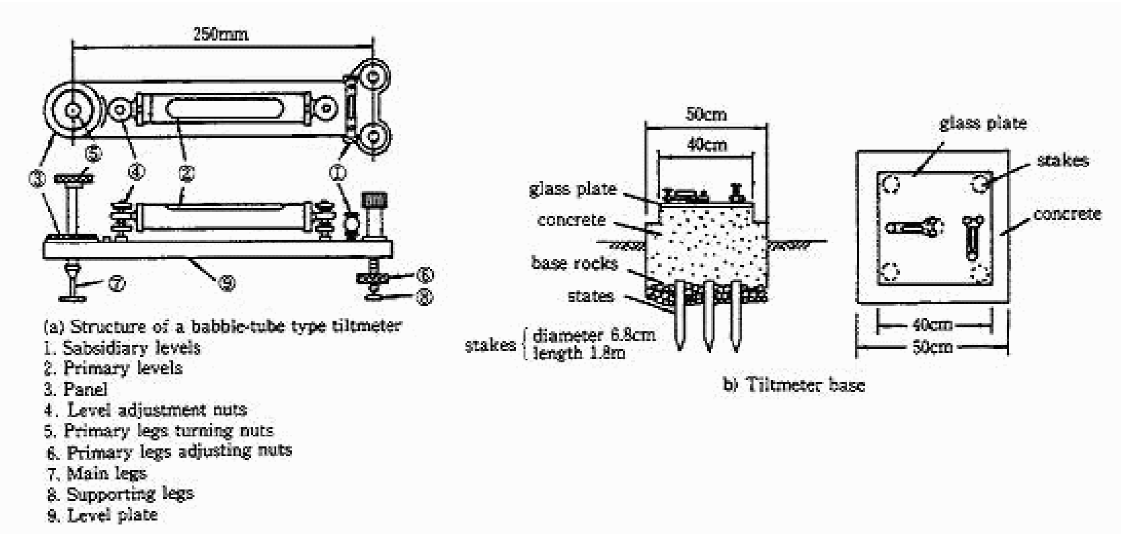

Fig. 16 Installation of tiltmeter

- **3) Simple Method to Measure Movements** One of the simplest methods to determine landslide movement is to drive wooden stakes across a tension crack along the direction of slide movement (Fig.18). Then attach horizontal boards to the stakes, and saw through the boards. Any movement across the tension crack can be determined by measuring the space between the sawed portions of the boards.
- **4) Determination of Movement by Surveying (Transverse Survey, Grid Survey, Laser Survey From the Opposite Bank, Movement Determination by Aerial Photographs, and G.P.S.).**

Transverse Survey:

This survey method establishes transverse survey lines across the landslide blocks with closely-spaced survey stakes. The survey stations should be established both within the slide and outside the slide on stable ground.

Grid Survey:

This survey method involves constructing grid lines across the entire landslide as well as stable ground outside of the landslide. The survey stakes are driven at the intersection of the grid lines.

Laser Survey from the Opposite Bank:

A control point is established along the opposite bank on stable ground, and survey stakes are positioned within the slide. It is most effective where the movement in large.

Movement determination by Aerial Photographs:

For landslides with a large component of movement, aerial photographic determination is the most useful. An accurate movement can be measured by annual or bi-annual flying.

G.P.S.:

Global Positioning System is the state of the art technology that uses signals from satellites to determine the three-dimensional positioning of the slide. G.P.S. has been used in recent landslide investigations where a high degree of success has been reported.

- **5)Automating Survey System** In the past, measurements of slope deformation have been performed manually. Recently, automatic survey systems using data loggers and computers have adopted (Fig.19). The instrument set-up in the field has been designed for easy installation, and is weatherproof, durable, maintenance-friendly and economical. (Fig.20) (Fig.21) (Fig.22) (Fig.23). Through remote control in real time and rapid geographical data processing, it is possible to store long term data accurately and effectively and would provide an early warning of slide activity, thereby reducing landslide hazard. Furthermore, the recent development in the informationalized constructions systems and adopting the safety control at the construction site using the real time facilitates the planning through construction stage (Fig.24).

There are three main advantages in using the automating survey system.

- 1. Surveillance of the conditions of landslide failure: Issuance and cancellation of landslide watch and warning announcement based on the velocity of movement, piezometric pressure and variation in the rainfall amounts. Prediction and forecasting of the landslide failure.

- 2. Understanding of the conditions of the landslide deformation: Chronological measurements of movement velocity. Determination of the slide plane depth. Determination of the relationship between the slope deformation and factors of slide occurrence (pore water pressure against the slide plane, critical pore water pressure related to the time of sliding, rainfall and snowmelt).
- 3. Effectiveness in determining landslide control works: Measurement of the amount of earth movement and pore water pressure. Measurement of the earth pressure affected by piles and collection wells. Determination of the effectiveness of construction.

(2) Investigation of Geologic Structure

In most cases, the investigation of geologic structure relies on exploratory borings; however in cases where the bedrock distribution is ambiguous or a better understanding of the regional geologic structure is needed, then a geophysical exploration (seismic survey, electrical survey and radioactivity survey) is combined with the boring data.

1)Borings

The majority of the borings drilled are larger than 66mm. Core samples are recovered from the borings and are stored in core boxes. Boring logs should be prepared along with photographs of the core samples. The boring logs shall include such information as: geologic and soil description; color; hardness; lithologic description; degree of weathering; alterations and fractures; strike and dip of bedding joints; boring conditions; initial and stabilized ground water levels; and rate of core recovery.

Geologic assessment based on the boring data obtained from the drilling site should include a discussion regarding the differentiation of moving earth blocks, semi-moving earth, and stable ground. Clays within the slide plane generally have a high moisture content, are highly sticky and plastic and are often associated with abrasion scars and slickensides. During drilling, squeezed earth could occur near slide plane. Slopes where advanced relaxation of the bedrock formation has occurred will often exhibit gentler slopes than that of the unaffected bedrock zone. Formations can bend or form a kink bend near the lower limit of this zone, and could develop into a slide plane. In translational dip slope slides, the slide plane in many instances will develop along a thin, weak bed of mudstone, tuff bed or coal seam sandwiched between hard and competent beds. Borings can sometimes easily miss these thin beds. Therefore, the possible existence of slide planes along there weak beds typically consist of about 10cm, and must be considered even though the boring may not indicate they are actually present.

Furthermore, using the data from the borings, the following information must be assessed or determined.

1. Evaluation of slide plane 2. Ground water level measurements 3. Ground water logging 4. Ground water tracer tests 5. standard penetration tests, Horizontal loading tests, In-situ tests such as in site permeability tests 6. Sampling for soil tests 7. Various geophysical logging

2) Geophysical Surveys

Geophysical surveys (seismic survey, electric survey and radioactivity survey) are conducted to understand the approximate geophysical conditions of the slide itself and the surrounding area. P-wave refraction surveys are the most common seismic survey. Other methods, such as S-wave and P-wave shallow refraction, are seldom used. Electric survey is the specific resistance method and is applied to determine the distribution of aquifer(s) and to understand the geologic structure. These surveys include the development of the geotomography method. A natural radioactivity survey is used to determine the locations of small scale fracture zones and cracks.

(3) Evaluation of Slide Plane

Determining the slide plane for actively moving landslides utilize the fact that the rates of movement differ significantly along the slide plane. Depending on the requirements for surveying accuracy and magnitude of movement, the appropriate instrumentation shall be selected from the following representative instruments;

1. Pipe strain gauge 2. Inclinometer 3. Multi-layer movement meter

1) Pipe Strain Gauge

P.V.C. pipes with strain gauges are inserted into the boreholes, and the movement is estimated by the change in the strain as the P.V.C. pipe bends. The accuracy of the strain gauge increases as the intervals of the gauge narrows, however, it is acceptable to widen the space as much as 1m for investigations involving very thick slide materials and when it is difficult to handle the survey extension wires. Two of the lowest strain gauges must be anchored into the bedrock below the slide plane so that data from within the intact formation can be obtained. Furthermore, annular space between the borehole and the pipe must be filled with concrete following the gauge installation. The instruments should last for one to two years (Fig.25).

2) Inclinometer

A grooved casing is inserted into the borehole extending into the bedrock formation, and have an adequate quality of grout placed into the borehole to assure a positive contact with the borehole. By lowering a probe equipped with a tilt sensor, deformation in the casing can be detected and movement of a landslide can be determined. An accurate measurement is possible where the deformation of a landslide is relatively small. As a landslide movement increases, the borehole and casing will bend making insertion of the probe difficult or will exceed the tilt detection limit of the instrument. (Fig.26).

3) Multi-Layer Movement Meter

several wires are anchored at different depths within a borehole with the attached wires extended to the ground surface. The magnitude of the displacement of each wire segment can be measured directly using a ruler. It is possible to install 20 to 30 wires per borehole. This method is not suitable for landslides with small displacement. This instrument is most effective where the slide movement is so large that some of the other instruments cannot be used. Applying the same principle, a vertical extensometer can be constructed by fixing a wire on the bedrock at the bottom of the borehole (Fig.27).

4) Other Methods

Other methods to evaluate the slide plane include: slide plane detection probe; creep wells; and sounding penetration test.

(4) Ground Water Investigation

Investigation of ground water, which is a driving force of sliding, includes determining ground water level, pore water pressure, ground water logging, ground water tracing test, pumping test, water quality analysis, electricity survey, geothermal survey, and geophysical logging (electric logging and radioactive logging). Based on the results of the above measurements and tests, ground water control works can be planned and designed.

1) Ground Water Level Observation

As a general rule, ground water levels should be measured in all the boreholes. In some of the more important boreholes, continuous rainfall data will be kept by an automatic recorder to determine the correlation between the slide movement and rainfall and ground water level, and will collect data on the ground water distribution and movement regime.

2) Pore Water Pressure

Ground water levels in boreholes will often reflect seepage from highly fractured formations or indicate the water level of a predominant aquifer. Therefore, for stability analysis, it is best to measure pore water pressure along the slide plane. Sometimes it is difficult to accurately estimate the depth of the slide plane. In such cases it is desirable to install piezometers in the beds with low seepage or low shear strength. The standard piezometers that are used in landslide investigations must be durable, and open piezometer water level type.

3) Ground Water Logging

Locations of ground water flow and flow directions can be determined by measuring the increasing specific resistance of ground water in flow over time. The measurements will be continued often lowering specific resistance of ground water by injecting a salt solution into the borehole. There should be at least two borings for ground water logging at the head portion of the landslide where abundant ground water is expected. The measurement results should be recorded along with the boring logs, and the relationship between the location of ground water flow and bed, and magnitude and variation of specific resistance of ground water should be discussed. Furthermore, the results of the analysis should be recorded along with the cross sections in order to understand the overall ground water flow (Fig.28).

4) Ground water Tracer Tests

Tracers such as a soluble dye, or inorganic chemicals (NaCl) are injected into a borehole. Water samples are then collected chronologically from springs, other boreholes, wells and ponds within or outside the landslide, and are analyzed for the tracer to estimate the ground water flow direction(s) and permeability. This data is used for basic information for the design of dewatering works.

5) Drawdown Test

In order to estimate the yield and to calculate the coefficient of permeability, water within a borehole is pumped to certain levels after raising the boring casing every 2 to 3m. A time-recovery curve can then be plotted using Jacob's and other formulas, and the coefficient of permeability can be determined.
6) Water Quality Tests
Water quality tests are an effective method to examine the distribution of the ground water regime and flow directions where the subject landslide is very large and the ground water system is expected to be complicated. Specific tests include determination of water temperature, Cl-, SO2-4, HCO-3, Na+, K+, Ca++, and Mg++ content, pH, alkalinity, electric conductivity, SiO2, and others. The test results are classified according to the analytical data and composition.
7) Geothermal Investigation

This procedure utilizes ground temperature measurements throughout the study area, including ground temperatures near the ground water veins. By measuring the temperature differences at non-ground water areas and near ground water veins, it is possible to isolate the ground water veins where the temperature difference between the two is large. By conducting the geothermal investigation in summer months or winter months where near surface ground temperature is influenced by air temperature, good results have been obtained for the isolation of relatively shallow ground water.

(5) Geotechnical Investigation (Rock Mechanic Tests)
In order to conduct slope stability analyses and to design appropriate control measures for landslides, physical properties such as strength of slide plane, location and depth of slide plane and stable ground areas must be determined. The following tests are generally performed; physical tests, Standard Penetration Tests, soil mechanic tests (unconfined compression, tri-axial compression, box shear, ring shear, and in-situ shear (along the slide plane)). In order to obtain the earth reaction coefficient for the design of the restraint works, there is a current tendency to conduct more horizontal loading tests and plate loading tests to determine the modules of deformation. Furthermore, the intensity and degree of alteration of the slide plane clays are evaluated by X-ray diffraction methods. The results have also been applied to analyze the origin of the slide plane.

3-4 Prediction of Landslide

(1) Landslide Distribution Map
Most of the new landslide are reactivated old failures in landslide terrain, and unless there are special causes, it is extremely rare that non-landslide terrain fails. Those topographic characteristics can be interpreted from aerial photographs and topographic maps, and be verified through field reconnaissance.

Furthermore, bedrock landslides and weathered bedrock landslides with past movement at the time of sliding is small, and sheared bedrock and topographic features related to the early stages of sliding that were subjected to creep deformation in the deeper portions often do not exhibit clear landslide topographic characteristics. Because of these reasons, double ridge topography associated with mountain deformation, parting ridges, breaks-in-slope, knick lines, distribution of old and scarps, bulging at the tip of ridge lines, discrepancy in the geologic distribution "following the investigation, geologic structure degree of shearing degree of creep and other factors must be considered when evaluating landslide topography.

Landslide distribution maps with the above descriptions are generally limited to small areas, however, recent regional maps covering the entire country of Japan have been published (Fig.29).

(2) Landslide Prediction
Now it is possible to predict the timing of a slope failure by interpreting the rate of deflection measured by extensometers placed across tension cracks of a slope. Failure predictions rely on extensometers placed across scarps, and areas will be considered "off-limits" when the rate of movement exceeds 2 to 4 mm/hour. Based on the change in the rate of movement, the following three methods are commonly used to predict the timing of landslide movement.

- 1) Graphic solution using the tertiary creep curve (Fig.30)
- 2) Graphic solution of surplus time using semi-log paper (Fig.31)
- 3) Method using a inverse number of rate of movement (Fig.32)