# ON DISPLACEMENT OF RIGID RETAINING WALLS

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## INTRODUCTION

Rigid retaining walls are commonly encountered structures. Though research on earth pressures dates back to 1873, considerable research is required to understand their behaviour (Ref.1). Very few predict earth pressures as a function of wall movements even for static case. Dynamic earth pressure problem is even more complicated. Very few experimental investigations using large walls are reported.

A program for testing a 20 m high wall has been drawn up at Roorkee. Details of this program have been discussed in this paper with respect to evaluation of information required for further improvements of static and dynamic earth pressure theories. Discussions and suggestions in this regard are expected to be of great interest to this Conference and of use to authors of this program.

## IDENTIFICATION OF AREAS OF EXPERIMENTAL INVESTIGATION

Rigid retaining walls move away from backfill during earthquakes which has been examined critically by Prakash (Ref.2). It has been recommended to conduct full scale tests to study the behaviour of wall during static and dynamic conditions.

### Static Loading Conditions

Couloms's theory does not provide earth pressure distribution. Rankine's theory predicts hydrostatic type of pressure distribution for smooth walls, which does not satisfy moment equilibrium.. Moment equilibrium is not used, because, pressure distribution along the wall back and assumed rupture surface are unknown.

Two theories are available to predict pressure distribution. The theory proposed by Prakash and Basavanna 1969 and revised by Basavanna in 1970 (Ref.3,4) assumes linear failure surface and cohesionless soils. It also assumes that vertical stress at a point in failure wedge is due to mass of soil column at that point,

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which is not true. This makes resultant earth force move away from the heel. The theory by Joshi and Prajapati (Ref.5) removes this error using method of slices to determine pressure distribution along assumed failure plane for active case. Using this, point of application of earth force is obtained by using moment equilibrium. It assumes direction of interslice forces, which is reasonable but needs to be verified experimentally. Pressure distribution predicted by the two theories have not been compared with test results.

Angle of wall friction is assumed to be between Ø/3 to 2Ø/3 for most cases, Ø being angle of internal friction of the fill. This leads to considerable variation in computed active pressures, especially for larger values of Ø. It is better to measure normal and tangential components of pressures on wall back at various points and obtain variation of angle of wall friction. Joshi and Prajapati (1982) have reported that active earth force by Couloms's theory at a particular angle of wall friction is minimum. This should be verified experimentally.

Many have reported that assumption of plane failure surface is reasonable for cohesionless soils and small angles of wall friction. However, clear failure surfaces do not occur for small wall movements and loose soils. For such cases, vertical and horizontal pressures within the fill at various points give direction of maximum shear stress and hence shape of potential failure surface. It can also evaluate pressure distribution along failure surfaces and direction of interslice earth pressures. Comparison of displacements&pressures at various wall movements will indicate whether rupture wedge acts like a rigid body. For rocky foundations, sliding or rotation about heel of the wall are difficult to get realized. For flexible foundations, a combination of sliding and rotation is likely. Therefore, test data regarding foundation stresses, contact pressures, translation and rotation of the wall are important.

Peak values of passive pressures on front side of wall are seldom of great interest as associated wall movements are too large. Wall movements are too small to mobilize full passive resistance in most cases. When stabilizing forces provided in the design do not allow sufficient wall movements for reaching active stage, pressures in between at rest and active earth pressures occur. Therefore, prediction of passive mobilized pressures as a function of wall motion is desirable for safe design of wall. There are very few experimental investigations reported about the same. Because of high passive pressure values, compressibility of passive wedge has to be considered. The soil element gets compressed under passive pressure before the pressure is transmitted to adjacent soil element. As such, measurement of vertical and horizontal pressures and displacements within the passive wedge is important.

Dynamic Loading Condition

Lack of experimental data about earth pressures under earthquake conditions, particularly for tall retaining walls is a great impediment in development and evaluation of earth pressure theories. Most points discussed for static case regarding wall friction, pressure distribution within fill and along wall back, contact pressure distribution along wall base and passive pressure distribution are studied in dynamic case also. Information available about shape of failure wedge under dynamic conditions is scanty. Mononobe-Okabe theory predicts larger failure wedge for larger horizontal accelerations. Based upon tests on retaining wall of about 3 ft. height, Nandakumaran (Ref.6) has reported that if a failure wedge is formed under static conditions, dynamic loading tends to cause larger movement of same wedge. More information is required in this regard.

In most cases, acceleration in the rupture wedge is assumed to be uniform. However, soil-wall interaction leads to certain magnification of response at fill level which may be of the order of 10% of reponse of ground at the base of wall (Ref.7). This depends on properties of soil-wall system and frequency content of dynamic loading. Further experimental investigations in this regard are required.

## DETAILS OF THE PROPOSED SET UP

Tests on 20 m high wall are too costly and time consuming to carry out extensive parameteric studies. Therefore, facilities existing in the University of Roorkee for testing 1m and 2m high walls will be employed to augment parameteric studies. Details of these facilities are reported elsewhere (Ref.6).

### Test Wall

RCC test wall cast in three segments of 7m length and 20m height with construction joints between them provided with polythene or tar sheets is believed to be adequate for creating plane strain conditions for the central segment. The wall will be designed for pressures predicted by Mononobe-Okabe theory. Each node on sides of the test wall shown in Fig.1 will have a pressure cell to measure normal and friction components of earth pressure and an acceleration pickup to record the response. Similar cells embedded along the wall base will measure contact pressures.

For measuring displacements and tilt of the wall, reference levels should be not influenced by wall movements. A masonry block situated outside the passive wedge with a rod anchored on this block and running upto the wall on intermediate roller supports will provide reference point for measuring horizontal motion (Fig.2). Vertical settlements are considered to be insignificant at the depth where vertical stress due to wall loads is 10% of that at the wall base. A cased bore hole extending upto this depth and housing a metal rod secured to soil below and extending upto ground level will provide reference to measure vertical movements (Fig.3). A plumb bob secured to wall at its top and extending upto ground level will be used to measure tilt of wall (Fig.4).

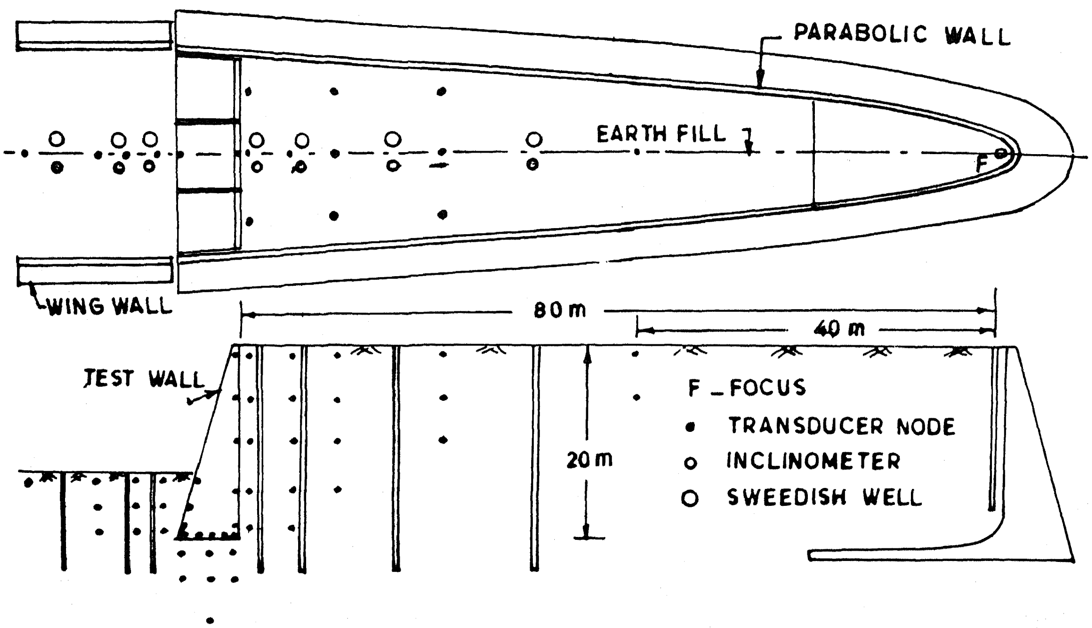


FIG.1 _ LAYOUT OF THE TEST SETUP

Earth Fill

Only cohensionless fills will be considered. Mechanised equipments like conveyor belt etc. will be required for fill replacement. Suitable tests can be carried out to check fill properties. Inclinometers and Sweedish wells, shown in Fig.1, will be used for measuring vertical and horizontal displacements within the fill to determine shape of failure wedge. Measurement of vertical and horizontal pressures at nodal points shown in Fig.1 will provide data for verifying interslice forces. At each nodal point an acceleration pickup will measure response of soil within failure wedge required in computing dynamic active pressures. Similar instrumentation is provided for the passive fill also. Pressure cells are embedded in soil below the wall to measure foundation stresses.

Test Chamber and Dynamic Loading

It is difficult to obtain high levels of excitation for 20m high wall with mechanical oscillators. Blasting appears to be appropriate excitation source. The test chamber should help to maximize propagation of energy through horizontal seismic waves. A chamber with parabolic wall with blast charges at the focus is proposed (Fig.1). Parallel wing walls will be provided to retain the passive fill (Fig.1).

It is difficult to create design seismic ground motions by blasting. Trial and error procedures with programmed ignition will

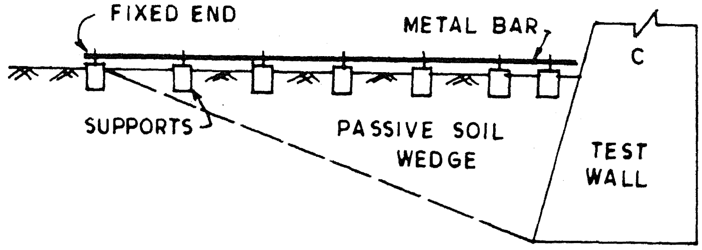


FIG. 2_ SETUP FOR MEASURING HORIZONTAL DISPLACEMENT OF WALL

be employed. The length of test chamber is believed to be adequate for creating plane strain conditions. Test data from buried pick-ups and pressure gauges will indicate how best this can be realized It is impossible to alter the predominant frequency of the site in such studies. However, limited energy supply is inadequate to excite soil to a significant depth.

Recently, contained blasting has been studied (Ref.8). A charge in a neoprene (plastic) container, which can expand to a volume many times its original volume without losing elasticity to allow its repeated use, is exploded. This directs greater portion of the blast energy in the form of horizontal seismic waves. This technique is not yet fully developed.

Dynamic loading for smaller walls can be provided by mechanical oscillators, dropping weights etc. for which facilities already exist in the University of Roorkee.

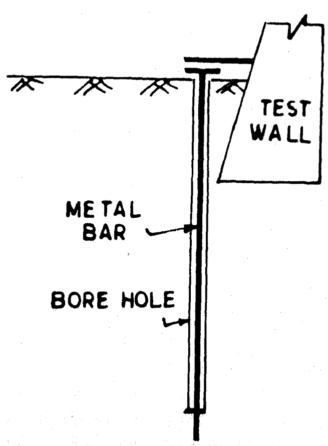


FIG. 3_SETUP FOR MEASURING VERTICAL SETTLEMENT OF THE WALL

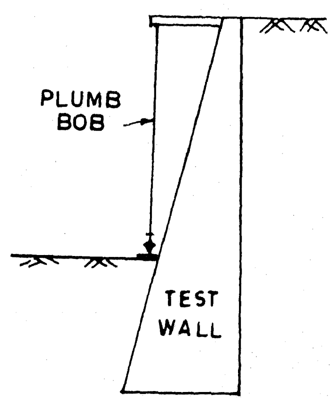


FIG. 4_SETUP FOR MEASURING TILT OF THE WALL

## Pressure Cells

To evaluate angle of wall friction along sides and base of the wall, cantilever type of pressure cells will be used (Ref.9). In case they are unsuitable to record dynamic pressures, diaphragm type of pressure cells will be used. Cells buried in the fill will be of diaphragm type. Leads of cells laid horizontally will be coiled at intervals to allow displacements without damaging wire connections. To minimize arching around cells, displacement of diaphragm should be small for a given cell diameter, which reduces sensitivity. To meet these conflicting demands, high sensitivity cells with clamped edge circular diaphragm created out of a solid stainless steel block will be used. Wheatstone bridge type of strain gauge grid with radial and helical type resistance gauges are employed to maximize sensitivity. To minimize interference of gauges with free field behaviour of fill material, size of the cell should be as small as possible. However, for coarse grain material, cells should be large enough with respect to grainsize. No such information is available for design of cells. Diaphragm diameter of ten times average grain size of the fill is considered adequate. Cells with 24 mm external diameter and 10 mm thickness have been fabricated in Roorkee for this purpose.

## Inclinometers and Sweedish Wells

They will be employed for measuring vertical and horizontal movements within the fill (Fig.1). Details of the equipment are reported elsewhere (Ref.10). Segments of 50 cm depth will be used for Sweedish wells to provide enough flexibility, especially near potential failure surfaces.

# ANALYSIS OF THE TEST DATA

Static test data will be helpful in comparing observed pressure distribution behind the wall with those predicted by theories proposed by Prakash and Basavanna (1969) and Joshi and Prajapati (1982). Observed normal and tangential pressures on the wall to determine variation of angle of wall friction. Observed horizontal and vertical pressures in the earth fill will assess actual mobilization of Ø. Orientation of maximum shear stresses within the fill based on actual pressures will identify potential failure surface. This can verify assumed shape of failure wedge and interslice forces for various earth pressure theories. Such findings are required in formulating simple and yet satisfactory theories.

Variation of passive pressure co-efficient for wall movements associated with active pressures is of particular interest. This test data will be useful in evolving suitable expressions to predict active and passive earth pressures as functions of wall movements, foundation compressibility, wall friction and base width of the wall. Dynamic tests will indicate whether a distinct failure wedge is formed for dynamic case or the static failure wedge itself keeps moving. This will verify the Mononobe-Okabe theory.

Actual measurement of response of wall and various nodal points within the fill provides a clear understanding of mechanics of the problem and indicate whether rupture wedge behaves like a rigid body. If it does not act like a rigid body, the very basis of the Mononobe-Okabe and other similar theories will be incorrect. The current day practice generally considers seismic coefficient of the site to be the same as that for failure wedge. If seismic coefficient appears to increase towards top end of the wedge significantly due to soil-wall interaction, dynamic earth pressures will be considerably larger near top end of the wall.

Displacement of wall is the most rational criterion for evaluating performance of wall. The principle of yield acceleration proposed by Newmark is the basis of such analysis (Ref.11). The knowledge of potential failure surfaces, mobilized angles of wall friction and shearing resistance of soil, pressure distribution along rupture surface and base of wall will provide excellent data for verifying and improving theories for displacement analysis of wall subjected to earthquakes.

## LIMITATIONS OF THE TEST

Under field conditions, ground motions are due to upward propagation of shear waves. Seismic ground motions on active and passive sides of the wall at foundation level are the same. However, this is not realized in the proposed test setup. The seismic ground motions on the passive side of the wall are likely to be of much lesser intensity compared to what is expected under earthquake conditions. Limited source of energy fails to excite sizable depth of soil below the wall. As such, vibration characteristics of foundation soil and their influence on response of wall-soil system expected during earthquakes will not occur during tests. No information is available on how to account for this discrepancy. Simulation of seismic ground motions is difficult. It is difficult to assess precisely whether a given dynamic excitation during the test is equivalent to a design earthquake. Induced accelerations within failure wedge due to blasting will vary appreciably with distance from source of excitation, which is not the case during the earthquakes.

## CONCLUSIONS

Adequate experimental data is not yet available for a better understanding of the static and dynamic pressures behind retaining walls. Tests on tall walls are practically not existing. Testing program reported in this presentation will provide sufficient data to evaluate distribution of angle of wall friction, active and passive pressures, mobilized angle of shearing resistance of soil along potential failure surface, orientation of potential failure surface, direction of interslice forces within failure wedge, displacement of wall required for full mobilization of active and passive pressures etc. Such findings are important in formulating better theories. The test results will be useful in evaluating and improving theories for displacement analysis of retaining walls.

The data from dynamic tests will be of help in understanding response of wall-soil system and its influence on earth pressures. Response of soil within the failure wedge will indicate whether assumption of uniform acceleration coefficient for the entire wedge is reasonable. The results will be helpful in considering the compressibility of soil below foundation and the passive wedge in earth pressure caclulations. Very few theories at present account for same.

This facility will be rather costly. However, test results are very valuable. This investment is worthwhile considering extensive use of retaining structures in a variety of civil engineering constructions. It is helpful in modifying various codes of practice for earth retaining structures. This setup can also be used to investigate dynamic at rest earth pressures not yet studied extensively so far. The programe has some limitations, especially in simulation of design seismic ground motions. However, comparison of such data with that obtained from tests employing shake table should be of help to make reasonable conclusions regarding the influence of the response of soil-wall system on earth pressures.

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