

# SEISMIC MICROZONING IN NEW ZEALAND

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## 1. Introduction

"Seismic Microzoning" means many different things to different people. There is always included the element of different damage in nearby areas, but how the differences arise, how we should study them, and how we should apply the results of our studies, are still uncertain.

To some people, microzoning refers to structural damage due to ground failure; faulting, slumping and liquefaction all belong in this category. To others, microzoning is the effects of the focussing of seismic waves by boundaries, resulting in modified ground damage and building damage.

A third very popular view of microzoning holds that it concerns multiple reflection of seismic waves in layers, with interference of the wave trains giving rise to maxima, where ground and structural damage will be accentuated.

Microzoning can be defined as the division of land areas into small regions of differing local geology for which differences in earthquake attack on structures are specified.

This paper is an attempt to set down aspects of microzoning in a logical manner, and to relate them. It also discusses activities here and overseas, and considers where microzoning and microzoning research in New Zealand should head.

## 2. Ground Damage, Relative Displacement, and Inertia

Seismic microzoning is the division of land areas into small regions, down to dimensions of a few hundred feet, for the purpose of describing differences in earthquake attack on structures. Three main mechanisms become immediately obvious in this context. The first mechanism of attack is ground failure. This takes in land slides, liquefaction, fault movement and slumping. Secondly there is the relative displacement attack, whereby the ground at different parts of an extended structure can move differently, causing structural failure. This relative displacement can be elastic, so that after the earthquake the ground is back as it was before. Pipelines crossing geological boundaries are targets for this type of attack.

The third mechanism giving rise to microzoning effects is variation of inertia attack. The inertia attack is caused by forces which are generated by ground acceleration acting on structural mass. Variations in ground acceleration give rise to variations in the inertia attack.

## 3. Microzoning and Microzoning Research

Microzones are being assigned in New Zealand on the basis of existing information. Research at present under way should lead to a more accurate definition of these microzones.

The specification of microzones on the basis of the three common mechanisms of attack is at present crude. Only a slow advance can be expected in microzoning for ground failure attack. However, rapid progress can be expected in microzoning for inertia attack. The variation of the inertia attack is possibly the least investigated mechanism, the one likely to show the most dramatic damage effects, and the one most amenable to an approach along the lines of conventional physical and engineering theory.

Structural attack due to ground damage should only occur in severe earthquakes, but inertia attack amplification will occur at all amplitudes, including those of moderate earthquakes. Thus inertia attack amplification will be a factor in many earthquakes.

The New Zealand D.S.I.R. Report "Microzoning for earthquake effects in the Pauatahanui area" represents the best that can be done on the basis of existing knowledge. It is likely to be of limited value to engineers.

## 4. Importance of Instrumental Studies

To be of any value, studies of the microzone inertia attack must relate to building damage, taking building character into account. Intensive studies of building damage after an earthquake yield limited information on inertia attack and the results obtained are usually capable of various interpretations. These objections arise from the complex dynamic characteristics of buildings. No damage to a building of 1 second period does not mean that there will be no damage to a  $\frac{1}{4}$  second one, and even if they have the same natural period, a shear wall structure and a frame structure can perform quite differently under earthquake loads. By the time one admits asymmetric buildings, or allows structural changes above a certain height, the situation becomes complex.

Any inertia attack study must start with

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ground motions, and deduce structural response, thence damage. It should concentrate on finding ways of characterising the response of any particular site.

### 5. The Mechanisms Involved in Modified Inertia Attack

At this point it should be noted that inertia generated ground forces control the relative displacement and ground failure effects, and that these will consequently show an inertia microzone dependence. Thus the inertia attack mechanism plays a central role in seismic microzoning.

Inertia attack mechanisms can be split into well defined groups. The major division is into wavelength dependent and wavelength independent processes. The former are comprised of interference, multiple reflection and resonance phenomena, while the latter are comprised of energy conservation and focussing effects. Under suitable circumstances any combination of these processes may be important.

#### 5.1 Interference

High intensity vibrations may be caused by several wavetrains fortuitously adding at some point in space to give a large resultant. The wavetrains all come from the prime energy source, but by different routes. A change in the waveforms even though they still propagate by the same paths, can change the interference pattern. This interference can happen for the incoming waves while they are still travelling in rock, and by its nature can potentially swamp the local geology effects in a random fashion. The process is the only argument against the "rock reference" concept (see section 6.4), and is deserving of investigation. The Hutt Valley strong motion network includes three rock based recorders as a first step in this direction.

#### 5.2 Multiple Reflection

This is a specific interference process, where the separate paths arise from multiple reflections from the interfaces between horizontal slabs of local geology. It was the first inertia attack process postulated.

#### 5.3 Resonance

In a sense resonance and multiple reflection go hand in hand, because an infinite horizontal slab behaves the same, whether treated as a mechanical resonator or multiply reflecting system. It is evident that a gully filled with alluvium will resonate, and that an excitation at a modal frequency will give a resonant rise of amplitude. However, a multiple reflection treatment of the same problem would not necessarily give the same answers. This is because boundary variations of the order of a wavelength in scale can diffract waves as well as reflect and refract them. Multiple reflection techniques are only approximate solutions of the wave equation, while resonant behaviour can be predicted from exact solutions of the wave equation.

#### 5.4 Energy Conservation

If a seismic wave progresses from a medium

of greater acoustic impedance to a medium of lesser acoustic impedance in a reflectionless manner, conservation of energy demands a greater amplitude on the softer medium, by a factor of the ratio of acoustic impedances. In the case of an abrupt transition a specific amount of reflection occurs and the ratio is of the square roots of the acoustic impedances. Reality usually lies somewhere between these two cases, but in any event it is a reason for expecting greater structural damage on softer ground.

#### 5.5 Focussing

Due to the laws of refraction, on traversing a boundary from a high velocity to a low velocity medium, a seismic ray will be bent towards the normal of the interface. Thus a curved interface can focus or defocus seismic waves. For instance, a semi cylindrical valley full of soil, with its rectangular face in the ground surface plane can potentially cause an abnormally high response along its axis, independent of wavelength. Focussing is the same sort of mechanism as that giving rise to a caustic curve in a tea cup (independent of colour) as it stands in sunlight.

### 6. The Techniques of Studying Modified Inertia Attack

Of the techniques evolved to predict variations in the inertia attack, some are specific with respect to mechanisms, while others are general in nature. Specific methods have been evolved for multiple reflection, where a postulated input is progressively delayed, attenuated, and added to itself; and for focussing, where ray tracing techniques are performed. For multiple reflection, the waveform and direction of propagation are variables, and for focussing the wavefronts are variable.

#### 6.1 General Methods

General methods started with the Japanese, who merely specified that flexible structures should be built on stiff ground, and stiff structures on flexible ground. This approach certainly avoids double resonances, but does not allow many sub divisions of ground types.

#### 6.2 Microtremor techniques

Studies based on microtremor observations have been actively carried out by the Japanese. These methods rely on measuring the frequency of the dominant ground vibration. This is assumed to be the frequency which will be amplified during a severe earthquake, and building design is based accordingly. The only work of a corroborative nature which has been done, consists of crude ground property measurements applied to a multiple reflection model. Varying degrees of success have been obtained.

The method should be viewed with some scepticism both because the mechanism by which microtremors acquire their dominant frequency is not known, and on account of the lack of corroborative evidence of a firm nature. Microtremors are at least partially induced by traffic and weather, and who can say that seismically unimportant characteristics will not dominate the microtremor process?

### 6.3 Brute Force Analysis

Some schools of thought favour a finite element approach for analysis of inertia attack microzone effects. Of course this is an approach which cannot be logically faulted. One merely obtains modulus and density data on a suitable three dimensional grid for the locale in question (the moduli being functions of strain), and using a large computer, follows the surface consequences of some bedrock motion. The practical and financial problems encountered in doing this may be large.

### 6.4 Small Earthquakes

There appears to be much merit in observing small earthquakes, in order to predict features of future larger ones. (If the modification was dependent on the direction of propagation, a representative selection of small earthquakes from different directions would have to be used).

Small earthquakes will encounter the same geological configurations in the same fashion as large ones, and will be modified by almost the same process. The only differences will be due to material properties being functions of amplitude. Thus deposits will tend to have lower resonant frequencies in large earthquakes due to a decrease in the shear modulus of soil at large amplitudes.

An uncertainty which must be cleared up before small earthquakes can be used confidently, and indeed before sense is made of other methods, is the precise nature of "rock reference". This term is used to stress the fact that it is the motion of the bedrock surface which drives the soil. Before soil surface motion can be deduced from any model, we must know the variation of the "drive" across the bedrock. The drive is certainly uniform over a small enough distance, but no field work on this aspect is reported in the literature. Before mechanisms can be deduced from any scaling method such as the use of small earthquakes, the character of "rock reference" must be known.

In this untouched field of small earthquake microzoning there is the question of analysis. One could contemplate measuring the ratio of peak accelerations of records, or better, the ratio of power spectra, the latter presumably showing up resonant phenomena. Our group wishes to obtain a model which can predict both horizontal components of ground motion in detail, given both horizontal components of bedrock motion. We feel that a person able to do this understands the processes, and is then in a position to generalise and to simplify. Amplitude and spectrum methods applied to one component do not lead to detailed predictions, apparently because one bedrock component can affect the other component on the surface.

### 7. Intensity Effects

The magnitude of the ground strain is an important parameter which enters microzone inertia attack studies. Hysteretic characteristics in the stress-strain relations of the ground can influence the amount of energy which is used in ground deformation and is consequently not available for building damage.

Non-linear characteristics alter the soil modulus and thence the natural frequency of a soil resonator. Both hysteresis and non-linearity become important at large amplitudes.

There are two aspects of this intensity question. One concerns changes in soil parameters as the intensity is increased, and the other concerns the lower and upper limits of intensity which must be considered.

If small earthquakes are used as a tool in studies of the inertia attack, they may be expected to reflect in a qualitative way, all important characteristics. That is, if a piece of ground behaves like a resonator of 1 second natural period and 10% of critical damping, in a strong earthquake, the small earthquake will correctly indicate a resonator. The frequency and damping indicated could be in error, and the appropriate correction would have to be applied as a matter of experience.

On the other hand, the range of strain in large earthquakes is likely to be restricted. Below the structural damage threshold we are not interested. At high levels, where the ground absorbs energy in failure and the inertia attack zonal contrast falls, such effects as subsidence and liquefaction may dominate, and once again we lose interest in the inertia attack. This is the second aspect of intensity referred to before.

Inertia attack then, will dominate microzoning thoughts for the smaller amplitude damaging earthquakes. Because small amplitudes are more common, modification of the inertia attack is a very important part of microzoning.

### 8. Scale of Microzoning

Nothing has been said so far about where microzoning ends and detailed site investigation begins. This is a controversial topic, but in view of the physical facts, guidelines can be set easily.

Where the problem is particular to a structure, it is one of detailed site investigation. On the other hand anything concerned with the ground alone is microzoning.

In the case of large buildings, two approaches are evident. One may regard the total response of the system from bed rock up, or one may predict the surface motion independently and apply it to the very local building - plus - foundation system.

The first method is analytically correct but may involve very unwieldy computations and be rendered very inaccurate by difficulties in assessing ground properties.

The second method is an approximation, but a readily applied one, and in all likelihood will give truer results. The surface layers have a great enough mass that the building will be driven by the surface ground motion. Foundations are easily analysed now, and the experimental small-earthquake method should give accurate surface motion predictions, given an assumed motion of the bedrock.

If the second method is adopted, detailed site investigation will extend to getting enough data to solve foundation problems, and

microzoning will concern the relation between basement motion and surface motion.

### 9. The Importance of Shear

In most records of strong earthquake acceleration, the maximum acceleration is attained during the s phase. Furthermore, in most records, the s phase is associated with predominantly horizontal ground motion. Again, the inertia attack on buildings is most important in the horizontal direction, because vertical acceleration amounts to an increase in the gravitational static load on the building (of maybe 50%) while the horizontal inertia loading during an earthquake is far greater than the usual horizontal loads due to wind.

Thus because they carry the most energy, and use it the most destructively, s - waves are of primary importance in the microzoning problem. Microzoning studies should concentrate mainly on effects due to shear waves.

In the softest soils, where microzone effects may be most pronounced, s-wave velocities may bear little relation to p-wave velocities. This rules out the use of p-wave velocity data to calculate s-wave velocities and resonant frequencies. Likewise it casts a doubt on the value of microtremor spectral peaks, because these could arise from p-wave resonances.

### 10. Earthquake Character

Ground motion in a particular earthquake depends on the character of the earthquake, as well as that of the ground. Thus the earthquake spectrum on rock, and the impulsive or noise-like character of the earthquake must be considered.

#### 10.1 Rock Spectrum

The attenuation of shear waves in rock increases with their frequency. Hence the peak of the spectrum on rock will shift to lower frequencies as a particular earthquake is recorded progressively further from the epicentre. In addition, because larger earthquakes involve larger source dimensions, it is plausible that they have their spectral peaks at lower frequencies.

Neither of these effects has been strictly quantified owing to lack of strong motion data. An impression of the existence of the second effect could be due to the fact that strong earthquake accelerations tend to be recorded at distance, and small ones are only recorded close to the source.

#### 10.2 Impulsiveness

It is possible for two earthquakes to have identical power spectra even though one is impulsive and the other more noise-like in character. They could have different response spectra and cause different damage.

One consequence of this is that in examining the effects of local geology on the inertia attack, choosing typical rock motions from a range of magnitudes and epicentral distances is insufficient. One must also select some "different looking" earthquakes for each magnitude and distance before a

representative picture is obtained.

One fact is abundantly clear - that more strong motion earthquake records are needed before a definitive pattern of rock vibration emerges.

### 11. Direction of Propagation

At first sight it appears that the transfer characteristics of soil layers will vary greatly from earthquake to earthquake because each earthquake approaches by a unique set of paths. However, considerable simplifications may be possible, since it may be permissible to assume that the basement is translating bodily, in which case the direction of wave propagation in the rock is irrelevant.

Consider such a system as that in Fig. 2. The bed rock excites the soil at point A, and we must ask what bedrock motion is important in the response. Points such as D will have little contribution, because the energy at D will be refracted at the rock-soil interface to propagate vertically. The main contribution will be from the region B - C, of about a quarter wavelength in the soil ( $\lambda_s/4$ ). Over this region there will be little change in the bedrock motion (even for horizontal propagation) because, typically, the wavelength in the rock ( $\lambda_r$ ) will be of an order greater than  $\lambda_s$ . Hence when ground resonance occurs it is reasonable to assume for the purpose of calculation that all points on the rock move in phase.

### 12. Microzoning Overseas

In seismic countries with advanced engineering works, the idea that local conditions can affect earthquake attack to a dramatic extent is accepted. The extension of these ideas into codes of practice has proceeded more slowly, but enlightened engineers consider site conditions and may modify design loadings accordingly.

In Japan, the concept of "dominant ground period" is accepted. In addition, for microzoning purposes, they tend to assign soils to one of 3 categories of goodness; rock, diluvium and alluvium.

Thinking in the USSR suggests modification of design loads according to soil stiffness and depth, and to building period. This is a way of recognising resonance.

The tendency in the U.S.A. is to reject microzoning as such, but to carefully investigate sub-site conditions for individual buildings. Sophisticated analyses of whole building-foundation systems have been undertaken.

### 13. Microzoning in New Zealand

The present situation in New Zealand is that engineers appreciate the dramatic changes in earthquake attack that local geology can cause. However, there is a marked reluctance to be bound by codes to take local geology into account. Such codes would act as a constraint which engineers would like to avoid.

At present designs are controlled on the basis of information gained by the usual site

investigation drillings. As this paper shows, this information would be complemented by information from an adequate microzoning map.

At the moment, microzoning in New Zealand amounts to the production of microzone maps of city areas by the D.S.I.R. These maps are the best that can be produced by the close co-operation of experts in the relevant fields.

The maps delineate zones which are progressively "worse", and as such are adequate for town planning. It is difficult to apply this information to designs but it does provide an overall geological picture of the site. The maps as they are will give no criteria for modifying design loadings. The D.S.I.R. divisions contributing to data for the maps are Geophysics Division, Soil Bureau, and Geological Survey. The Physics and Engineering Laboratory are involved at the stage at which data are co-ordinated and interpreted.

Engineers cannot be blamed for seeing a depressing picture in the information now available, but may be heartened to know that research proceeds at Auckland University, Canterbury University, and the Physics and Engineering Laboratory.

All three institutions have attempted to make sense of micro-tremor observations, with little progress as yet. It could well be that microtremor spectra may give building periods adequately, but not ground natural periods.

In situ shear wave properties are being studied by Physics and Engineering Laboratory and Canterbury University, the Physics and Engineering Laboratory current work aiming at shear velocity profiles down to bed rock. Physics and Engineering Laboratory, and in a smaller way Canterbury, are trying to carry out strong motion measurements on soil, because this must be the final arbiter in theories of inertia attack modification. To date only one such measurement has been made. The soil at Physics and Engineering Laboratory, in a 0.1g earthquake, has been shown to have a 0.55 second natural period. Insufficient is known about the local ground conditions to calculate this resonant period.

Auckland workers have concentrated on laboratory measurements of dynamic soil characteristics, and this will be a vital factor in those microzone investigations of interest to engineers.

Theoretical investigations of ideal geometries at Auckland and Canterbury have given insight into approximate mechanisms, in the same way that shaking a plaster mould containing jelly has at Physics and Engineering Laboratory.

Mention must be made of the Physics and Engineering Laboratory projections of the appropriate pattern for inertia attack research.

It is hoped that work will proceed in three stages; ground models valid for small earthquakes, ground models valid for severe earthquakes, and modification of the code. One critical advance expected is the determination of ground character by direct measurement during frequently occurring small earthquakes. This gives a low amplitude model of the ground.

A further critical advance will lie in learning how to modify the low amplitude models by taking into account the hysteresis and non-linearity of soils at the high strains which occur in destructive earthquakes. Modifying the code in accordance with the strong motion model should then follow easily.

There is enough diverse research effort being made that advances in microzoning seem certain, but it must always be borne in mind that the inertia attack picture is incomplete until strong motion accelerograms are obtained, and that both strong earthquakes and strong motion accelerographs are sufficiently rare that some time must elapse before enough data is forthcoming. For the Wellington area effective strong motion data is expected at intervals of about eight years. However, the small earthquake techniques which are under development will have useful events about once a week.

#### 14. Microzoning for Engineers

The fact that damage in earthquakes can be a dramatic function of local ground conditions is now established beyond doubt, Caracas and Manila being prime examples. It seems reasonable that knowledge of the cause of these phenomena must be of benefit to humanity, but how do we apply such knowledge? Town planners could undoubtedly shuffle things so that areas prone to liquefaction become recreational, and so that centres of commerce and administration, which attract tall buildings, are on the best available ground. However, town planners may have to weigh aesthetic values against earthquake probabilities, and who can blame them for belittling an event of low probability?

We can operate through the design engineer in a completely automatic way by modifying his design code. This would penalise the owner who insists on a building inappropriate to the site, by requiring higher design loads, and hence a more expensive structure. Microzoners, and codes, would take into account the possible surface motion, leaving the engineer to deal with the response of the building-foundation system to that motion.

One can justify such an approach by comparing the mass of soil with that of the building. From this point of view it is seen that during an earthquake, surface motion will be effectively independent of the structure.

This approach is urged as an alternative to the engineer attempting to evaluate the total system from the bed rock up. The latter could be more expensive and involved, and also less accurate.

The day may come when the microzoning map in its present form has transparent overlays supplied. These would carry contours, perhaps of ground resonant frequency and/or ground amplification, or perhaps derived parameters. The code would refer to these values, and ask that design loads be modified according to the values. Then, who knows, we may see a city area without buildings between three and ten stories, surviving an earthquake without the selective damage that has occurred during recent earthquakes.

### 15. Summary — Inertia Microzone Attack on Structures

The intensity of the microzone inertia attack increases with the softness of the soil. The depth of soft layers must be sufficient to bring the first resonant period up to a value at which considerable vibration is occurring in the underlying rocks. It is thought that the spectrum of rock vibration has a broad maximum centred on a period which increases with increasing epicentral distance and probably with earthquake magnitude. Hence the minimum depth of soft ground for severe microzone effects should increase with increased distance and probably also with magnitude.

For earthquakes with increasing intensity of rock vibration microzone effects should remain very pronounced until soil strains reach a level at which there is a large loss of energy due to plastic deformation or until there is damage by rupture or liquefaction. Hence for moderately severe earthquakes we expect large local increases in the inertia attack on sufficiently deep layers of soft ground. During very severe earthquakes we expect that local increases in the inertia attack will be much reduced by the energy absorbed during plastic deformation. As the earthquake intensity is increased there may be a small or a large range of intensities at which resonance is limited by plasticity before the intensity for damage by rupture or liquefaction is reached.

### 16. Conclusion

This paper has shown how inertia attack variations arise, how they can be studied, and how they are being studied. Hopefully, it has outlined the present critical points in inertia attack studies, and encourages a big push at these points.

The benefits to the community of taking local effects into account will be great, and this paper is intended to give engineers an overall picture of these effects. Designing for local ground effects is a constraint on the engineer, but one which is likely to be incorporated into existing constraints, and one which should have economic and humanitarian benefits for the community.

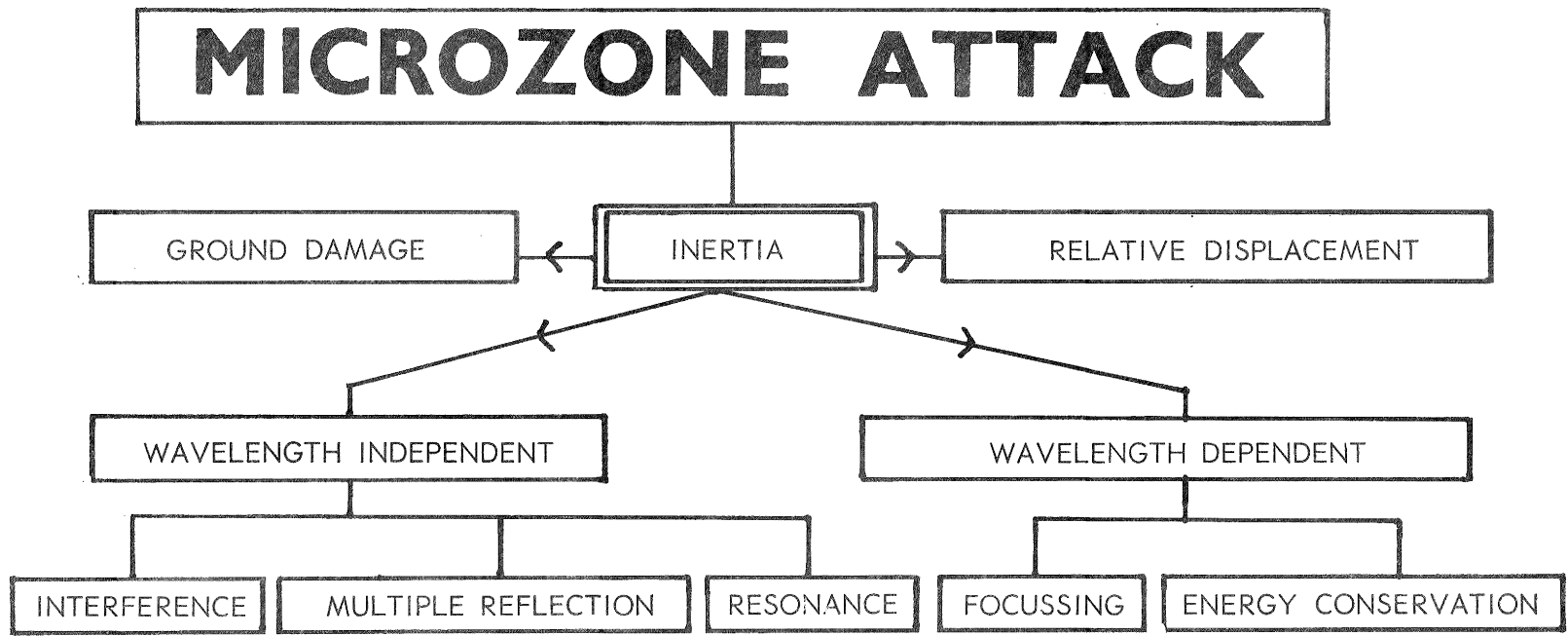


Fig. 1. Block diagram—microzone processes.

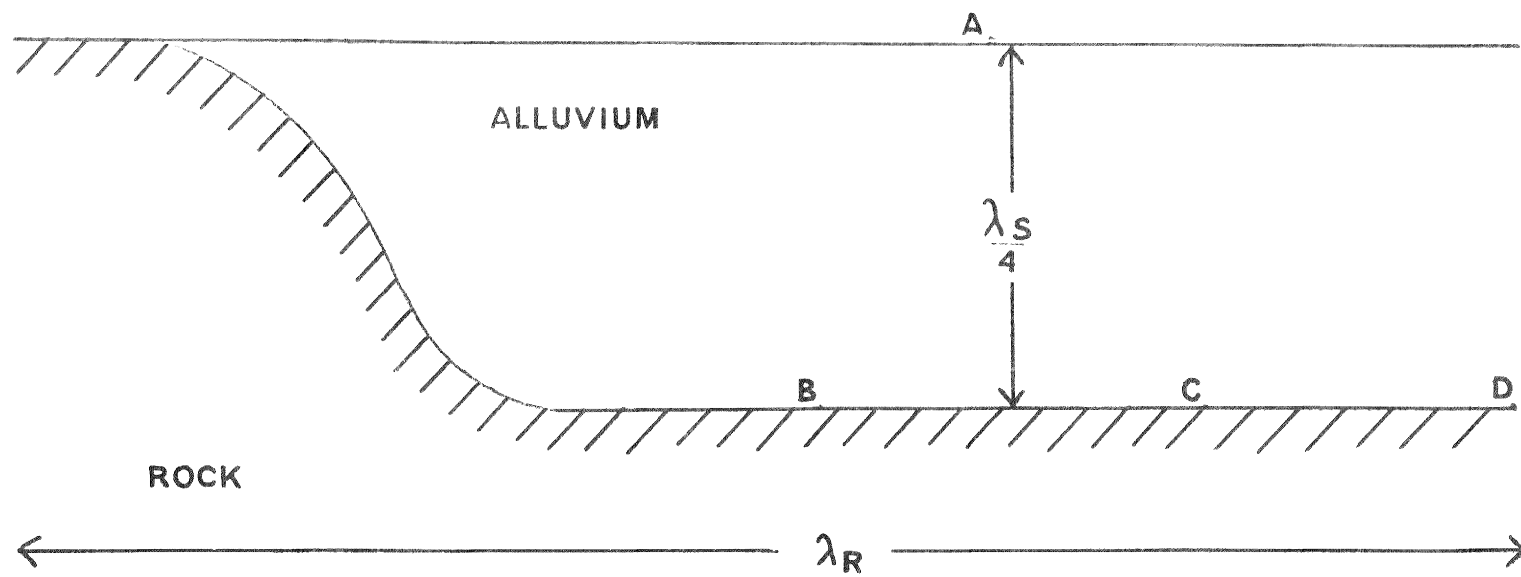


Fig. 2. Soil motion at A is primarily due to rock motion in the region B-C.