DETERMINING THE EARTHQUAKE RESISTANCE CHARACTERISTICS OF SEGMENTAL PAVING

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SUMMARY

This paper reviews the important characteristic of fully flexible segmental paving as being the essential requirement for earthquake resistance. Unlike other types of paving, even if the fully flexible segmental paving system suffers devastating distress by an earthquake, repairs are relatively simple and the most expensive item, the segmental units themselves, are reusable. An earthquake resistance scale for paving is suggested and with the use of fully flexible segmental paving purpose-designed emergency routes for use immediately after a devastating earthquake are proposed.

The paper also introduces a specialist research project which by its three phases seeks to determine realistic parameters and values for recommendation of earthquake resistance of various types of paving. The three phases are respectively; computer simulation, full-scale simulator tests; and long-term monitoring of representative sections of paving in earthquake sensitive areas.

Conclusions reached include the potential for saving large sums of money both in the easier repair of paving following an earthquake, and in savings through reductions of actual damage caused and of significantly greater importance, reductions in the potential for loss of life by using segmental paving in earthquake sensitive areas.

CONCEPTUAL

Segmental block paving systems are fully flexible and are therefore more "forgiving" of human and natural error than rigid concrete or flexible asphalt paving. This paper reviews this important characteristic but develops the concept further. It is argued that because of this forgivability fully flexible segmental paving systems have considerable benefit if used in areas of known earthquake activity. It is well known that minor earthquake activity can cause cracking or tearing in other paving procedures but the sand jointing and sand bedding of segmental paving systems should accommodate such movement without distress. Unlike with other types of paving even if the segmental paving system suffers devastating distress from an earthquake, most if not all of the segmental units themselves could be reused in the repair. The cost implications of being able to utilize segmental paving units even after the most severe earthquake is also discussed.

A need for an earthquake resistance rating for segmental paving is developed. Not only will such a rating be of value in considering possible reductions in future maintenance costs or in insurance fees for paving but it is also proposed that such a rating might cause segmental paving systems to be specified for roads specifically designated for emergency access. With this in mind it is noted that segmental paving systems and buried services under a segmental paving can be speedily repaired by hand if necessary. Hand repairs to severed and therefore dangerous gas lines is also possible. In such cases the use of machinery could be detrimental.

The paper also introduces the purpose-designed multi-interest research project designed to determine meaningful parameters and values needed for the recommendation of an earthquake resistance scale for segmental paving systems. The research project will be centred in Southern California because amongst other things it has one of the most developed built environments in the world which is subject to ongoing earthquake activity. Whilst there has been little or no research to date on the effects of earthquakes to paving, Southern California is convenient for the use of earthquake research facilities and specialists who have been involved in considerable

research into the effects of earthquakes on buildings. It is hoped that certain principles learned by their work would apply to the effects of earthquakes on segmental paving systems.

The research project is to comprise of three separate but inter-related phases. The first phase will use computer modelling to simulate the effects of vertical and horizontal displacements caused by varying the distance from an epicentre and by varying the intensity. The second phase is designed to study full-scale simulation tests on purpose-made sections of segmental and even other types of paving. Use of an earthquake simulator, together with any associated technical expertise and instrumentation, will be made. The third phase involves long-term monitoring of movement of representative sections of segmental paving in-situ before and after an earthquake. Sites for this third phase will be located at paved areas intended for a variety of uses throughout Southern California.

The paper leads to the conclusion that there are several benefits in the deliberate specification and use of segmental paving systems of a known earthquake resistance rating in areas of known earthquake activity. These benefits include the potential for saving considerable amounts of money in subsequent repair and reconstruction. In addition the possibility also exists of saving lives by maintaining access after a severe earthquake for emergency traffic. Segmental paving systems might also save life because they allow rapid repair of severed gas lines which can be expedited by hand if necessary.

THE FORGIVING PAVING SYSTEM

Small element segmental paving has been aptly described as "forgiving".[1] The term is used primarily to describe the ability to carry load even if the design assumptions are not achieved or no longer relevant. Segmental paving is however forgiving in several other ways. For example it is forgiving even when subjected to severe overloading or when there is a lack of adequate support for the applied loads. Such unfavourable conditions usually compact support layers under the segmental paving system which in turn deforms the surface. Even in such a condition the segmental paving system is still able to serve its function of load carrying.

Segmental paving is also forgiving of human design and construction errors. Many examples could be cited of segmental paving continuing to function even though the structural support layers were not constructed to the same specification at all places. The resulting differential surface deformation can easily be repaired. Areas of segmental paving most seriously affected can readily be taken up allowing relatively simple and inexpensive repair to the sublayers to be speedily carried out. In addition the original pavers can be reused, maintaining the aesthetic feature of the pavement as a whole. Similar errors with rigid concrete paving or with flexible asphalt paving would require expensive and time-consuming repairs.

segmental paving is also forgiving of changes in designed use. For example a segmental paved area designed for car-parking might be used for the loading and storage of heavy industrial equipment. Such use might also require it to carry heavy trucks and fork-lift vehicles. Even though the paving might deform under such loads, it usually remains functional. Upgrading can be done by temporary removal of the segmental units allowing reworking or strengthening of the supporting soil.

Small element segmental paving is also forgiving of environmental changes. The subgrade upon which the segmental paving system rests may not always remain static. Highly cohesive material swells and shrinks due to changes in moisture content. Great changes in thermal conditions can cause movement. Other environmentally related movements might be caused by frost heave, expansive soils, soils with a collapse potential, or with a high organic content.

However the most dramatic environmental movements of the earth are caused by earthquake activity. It is obviously neither possible nor economically desirable to attempt to design any paving system to be completely resistant to the effects of a major earthquake. However of the many thousands of earthquakes which occur daily around the world few cause devastation. Most are not felt and do little damage. Because segmental paving is fully flexible it is likely that it is much more forgiving of earthquake activity than any other method of paving.

A NEED FOR AN EARTHQUAKE RESISTANCE RATING FOR SEGMENTAL PAVING

Segmental block paving continues to gain popularity around the world because of its versatility, aesthetic appeal, need of minimal maintenance, and its ability to enhance the value of adjacent property. In the event of an earthquake of such an intensity that damage occurs most of the benefits of segmental paving will not be diminished. Even in a devastating earthquake, unless liquefaction of subgrade soils under the paving takes place, the paving units are unlikely to be damaged or lost. Repairs to the less expensive support layers is much simpler and less costly than the reconstruction which is invariably required with other paving methods.

It is hoped that if a meaningful earthquake resistance rating scale for segmental paving could be developed, property insurance costs could be reduced. It is also believed that such a scale would become an important factor in the deliberate choice of segmental paving for emergency access roads in areas prone to sever earthquake activity.

SCOPE OF THIS PAPER

This purpose of this paper is to discuss the forgivability of segmental paving in terms of its potential for earthquake resistance. It presents arguments for the specification of segmental paving in areas of known earthquake activity. It also introduces a purpose-designed multi-interest research project designed to determine and recommend an earthquake resistance scale for segmental paving. The research project is to be centred in southern California because it has one of the most developed built environments in the world which is subject to ongoing seismic activity. The paper leads to the conclusion that by the deliberate specification and use of segmental paving of a known earthquake resistance rating in such areas, there is not only the potential for the saving of considerable amounts of money, but also for the possibility of saving lives by maintaining access for emergency traffic through minimal repairs which could be undertaken by hand if necessary.

SCOPE OF THE RESEARCH

A multi-disciplinary research project designed to rate the suitability of segmental block paving in terms of its earthquake resistance has been conceived. It comprises three phases, namely:

1. Computer simulation of vertical displacements relative to time caused by an earthquake,

2. Laboratory simulator tests on full-scale section of paving subjected to various earthquake movements.

3. Long-term monitoring of representative sections of in-situ paving under earthquake conditions in the Los Angeles area. (This area was chosen because of the location of the principle research team members and the area is typical of an area with the potential for severe earthquake activity)

SPECIFIC GOALS OF THE RESEARCH

The following are the specific goals of the research project.

1. Determine the limit of zero defect due to earthquake activity.

2. Identify the limit of earthquake intensity beyond which repair is necessary to ensure emergency access.

3. Determine the energy input into a fully flexible paving system according to both intensity and distance from the epicentre.

4. Identify hand-methods for emergency repairs which might be necessary immediately after a devastating earthquake. The methods will include hand repair of buried services.

EARTHQUAKE CONSIDERATIONS

It is an undeniable fact that during the millennia of human experience earthquakes have caused considerably devastation. Over this time much has been learned and incorporated into design and construction practices to render buildings less susceptible to earthquake activity. Ancient civilizations may have incorporated various measures in their design to reduce the impact of an earthquake. The ancient Cyclopean walls found in South America are examples of the use of un-mortared interlocking stones of various sizes for wall construction in active earthquake areas. [2]

The most popular paving of the ancient civilizations which remains to this day was made of dressed stone blocks of random sizes. The stone blocks were either set on sand and sand jointed or were set and jointed with flexible bitumen. Since sections of this type of paving have survived to the present time it is concluded that such paving has considerable earthquake resistance.

It might be of significance in respect of the potential for earthquake resistance of modern segmental paving to reflect that ancient cities which remain to this day used segmental stone paving for important streets. Ancient peoples apparently preferred fully flexible paving to a rigid cemented or a flexible bitumen stabilized systems. Some researchers suggests that the variable sized interlocking blocks used for walls in some parts of the world were deliberately used because of their inherent earthquake resistance. (e.g. [2]) If this conclusion is valid it is possible that the variable sizes of segmental stones used for street paving could also have been deliberately chosen for their earthquake resistance.

Few buildings from the ancient past remain to this day. The majority were probably destroyed through war, pillaging, or more likely by earthquake activity. However there are still many examples of ancient fully flexible segmental paved roads to be found in many locations around the world. It is not known if there was a deliberate attempt to incorporate earthquake resistance into the design and construction of ancient roads, but the proof of millennia of history which has of necessity included much earthquake activity, suggests the conclusion that segmental paving systems have inherent earthquake resistance characteristics.

In modern times much research has been carried out to study the effects of earthquakes on buildings. However there is no record of any research having been done to determine the response of any type of paving to earthquakes. This fact was ascertained through conventional literature surveys and through personal discussions with some pavement engineering researchers. (e.g. [3], [4], [5], [6], [7], [8]) This fact is not considered surprising because research emphasis has concentrated on buildings because the potential for loss of life and limb through earthquake activity is far greater than from affected paved surfaces.

Research into the earthquake resistance of pavements is however necessary because the collective cost of reconstruction and repairs to public paved areas and private driveways following earthquakes is considerable. [9] With rigid and flexible pavements, reconstruction is often necessary following a major earthquake. Even the repairs necessary after a small earthquake can be both expensive and time consuming. By comparison segmental paving has the potential for repair rather than reconstruction. This would be the case even after a major earthquake. Repairs following a smaller earthquake are likely to be minimal or even not necessary at all.

NEED FOR EMERGENCY ACCESS FOLLOWING AN EARTHQUAKE

An unrecognized attribute of fully flexible segmental paved areas is the ability to provide access to devastated areas with minimum repair. In most cases any repair necessary to enable the segmental paving to provide emergency access could even be done without the use of machinery if power is not available.

Following a severe earthquake there is the immediate need for rescue teams to travel around the devastated area. Both rigid and flexible paving are not as forgiving to earthquake effects as fully flexible segmental paving system. For example slabs of rigid paving tend to break or move relative to adjacent slabs rendering vehicular access difficult or impossible. (A photograph (figure 1) taken after the 8.3 (Richter) earthquake in San Francisco in 1906 shows this possibility. [10]) Flexible asphalt paving systems may tear and deform. By comparison

individual pavers of a fully flexible segmental paving system are protected to a great extent from the effects of earth movements by the jointing and bedding sand. Should access be disrupted, restoration is easier with a flexible paving system than with either a rigid or flexible pavement. With rigid and flexible pavements machinery is usually required to break out sections of paving blocking vehicular access. Machinery is also needed to repair the facility and time for curing of materials before use could be another undesirable factor.

Since it is relatively easy to take up sections of a seriously deformed segmental pavement, buried services can be easily found and repaired by hand methods if no machinery is available. This is of vital importance where natural gas or fuel pipelines are fractured. Under normal use it is difficult to remove individual pavers from their matrix but an earthquake would loosen jointing sand allowing easier removal of individual units. The bond between individual paving units for which the jointing sand is the medium, rapidly re-establishes itself by the action of the environment and by trafficking.

SIMULATING EARTHQUAKE ACTIVITY

Earthquakes are triggered by the action of giant shear zones along fault lines. All major faults are not single breaks in the rock but involve movement of several roughly parallel lines of activity over a wide zone. Movement normally takes place inducing strain into rocks.

An earthquake is produced when the elastic strain in rocks in the earth's crust rises to such a level that sudden rupture occurs. This causes vibrations to radiate from the point of rupture. The vibrations can range from barely noticeable to catastrophically destructive. The Roman historian Senaca (4BCE? - 65) considered that earthquakes shook the earth in three ways, from side to side, up and down, and by a combination of the two. [11]

It is now known that six kinds of shock wave are generated in the process. (e.g. [12], [13]) Two are classified as body waves which travel through the earth's interior. The other four are surface waves. The waves can be either compressional or transverse shear. Compressional waves are called "P" waves and induce backwards and forwards oscillatory movement in particles in the same direction as the wave. Transverse shear waves are also known as secondary waves or "S" waves. S waves induce movement in particles perpendicular to the direction of their travel. P waves always travel faster than S waves and are the first to be recorded on seismic equipment. Rayleigh waves are so-called after Lord Rayleigh, the British physicist who was the first to describe surface waves. Love waves, "L" waves, are named in honour of A E H Love, a British mathematician who first described longitudinal shear waves which vibrate the ground horizontally at right angles to the direction of the wave.

Earthquake intensity at the point of its epicentre is measured by several scales including the Modified Mercalli and The Chinese Classification, but the most common scale used around the world is the Richter classification. It utilizes a logarithmic scale that runs from 1 to 9.5.

Earthquakes can be caused by tectonic activity, from volcanic eruptions, or can be artificially induced by mining activity or nuclear explosion for example. The most devastating earthquakes are caused by tectonic activity resulting from adjacent plates sliding past or moving under each other. The San Andreas Fault in California, which is North America's most earthquake-prone area, is an active example of movements of tectonic plates. Another kind of tectonic earthquake are known as mid-plate earthquakes. These occur infrequently but can cause massive damage. Examples of mid-plate earthquakes are the massive tremors which occurred in Missouri in 1811 and 1812, and in South Carolina in 1886. The former was of such intensity that it was felt 1000 miles away and produced movements which rerouted the Mississippi River. [12], [14] Geologists believe that mid-plate earthquakes are the result of forces tearing a plate apart, which was probably the cause of Africa's Rift Valley. (e.g. [13]

Earthquake induced waves can cause liquefaction of some soils. Should this happen the soil looses its bearing capacity and the effects of gravity causes buildings to be swallowed in a similar way to quicksand. [12] Because of this sensitivity of certain soils it is hoped the research project introduced in this paper will establish the critical mass per unit volume of the paving system beyond which liquefaction becomes critical.

Because of the more serious affects of tectonic earthquakes the research will seek to simulate tectonic rather than volcanic or artificially induced earthquake activity. However the research findings made through tectonic earthquake simulation on segmental paving systems are hoped to be directly applicable to volcanic and artificially induced earthquakes.

HAS CIVILIZATION COME FULL CIRCLE?

Segmental block paving is now used throughout the world as a aesthetically pleasing yet fully functional paving system for all leading applications. There is still some debate about its suitability for high-speed roads although several examples can be cited where it is being used even in such a demanding application. Most specifiers do not currently envision segmental paving for use by high speed traffic.

The history of paved streets can be briefly traced to show their complementary function within any civilized community. According to most dictionaries the very word "street" is derived from "paved with stones". (e.g. [15] For the greater part of human history paved streets provided a place for much of the social intercourse by the local community. Children played on the streets, trade was conducted on the streets, and the elderly sat and watched the activities of the community. The street also served the immediate and the greater community in a secondary role as the carrier of transport for people and goods. Even the dead were transported by the streets to their final resting place. Streets have traditionally been important in facilitating community life.

With the advent of the motor car however, the traditional primary role of the street was relegated to a secondary or even to a non-existent role. As the speed and weight of transport vehicles increased so the potential for danger increased proportionately. In time motor cars became the preferred means of transport and in many communities universal ownership was possible. In time people effectively turned their backs on the street preferring to focus their social activities elsewhere. This had the result of segregating the community into separate households and the anomaly of loneliness in an urban community was one of the results.

However in recent times some residential street have again become centres of social life for the street community. Segmental block paving is playing an important role in this urban restoration. The human scale of segmental paving systems together with its aesthetic appeal are principle factors in the increasing use of segmental pavers for urban renewal. As seems apparent from the evidence of pavements still extant from ancient civilizations the use of fully flexible segmental paving systems gave substantial earthquake resistance. Modern segmental paving systems should have the same inherent potential for earthquake resistance, a consideration which has not yet been recognized.

THE MULTI-DISCIPLINARY RESEARCH PARTICIPANTS AND ACTIVITIES

Principle research facilitators: Dr John Clifford, specialist paving consultant Cape Technikon, South Africa, and Larry Green, President of Systems Paving Inc., Newport Beach, southern California.

Use of University of California's earthquake simulator is envisioned. This is currently the largest facility in the world. Prof Carl Monismith, and John Harvey of University of California, Berkeley might choose to become involved.

Monitoring of existing segmental paving for empirical justification will be conducted on sites laid or supplied by Systems Paving, Inc., of Newport Beach, California and Acker-Stone Inc., Corona, California. Sites chosen will be within the earthquake potential area of southern California.

Advice and a review of the findings of the research project is invited form interested parties.

CONCLUSIONS

Whilst the benefits of fully-flexible segmental paving to accommodate slow-creep movements caused by fault strain is more apparent, the suitability of the system to violent movements has not yet been considered.

The research project is expected to provide data for rating segmental paving systems in terms of its response to earthquake actively. The research will also identify and enumerate methods for emergency and longer-term restoration. It is intended that the findings will lead to the drafting of guidelines for relatively simple and inexpensive emergency repair procedures which might be necessitated following a major earthquake. The research should lead to further investigation of the hitherto unrecognized potential of the use of segmental paving systems in areas of the world with a known earthquake potential.

Because of the location of the research the findings will be specific to southern Californian conditions. However it is expected that the findings will be universally applicable especially to areas with high earthquake activity such as Japan and New Zealand. Designers of paving in areas of the world where earthquake activity is a factor to be considered, have not recognized the benefits of segmental paving systems in terms of earthquake resistance. It is expected that this research will provide data for initiating meaningful negotiations with insurance companies for possible reductions in premiums where segmental paving is used in known earthquake activity zones. The research is also expected to empower civic leaders to specify segmental block paving for emergency routes as part of the design for anticipating earthquake restoration.

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FIGURE 1. Photograph taken after devastating earthquake showing forgiveability of segmantal paving.

