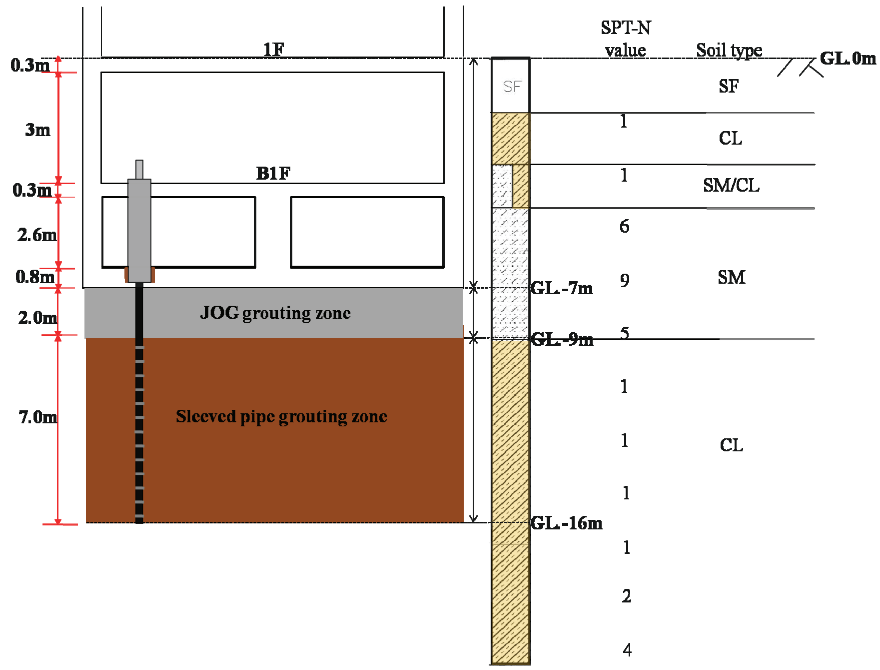

FIG.1. Subsoil condition and grouting zones

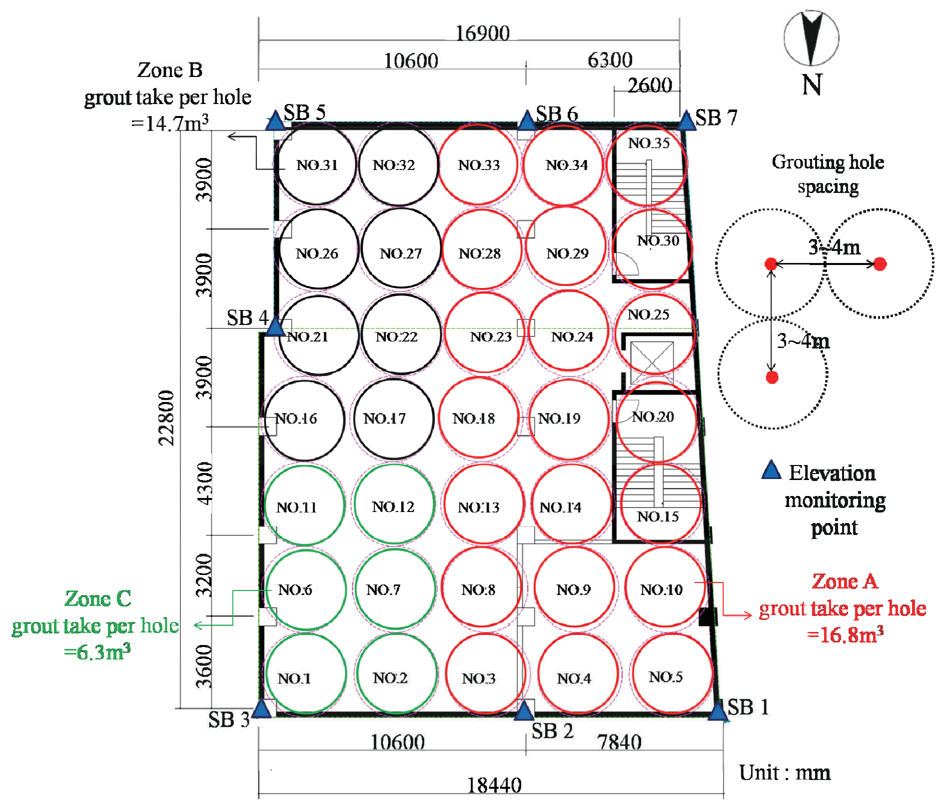

FIG.2. Grout hole layout in basement

Table 1. Grout mix for sleeved pipe grouting

Cement (kg)	400
Lime (kg)	20
Water (kg)	866
1000 liters	

As soon as the soil is hard enough to act as a reaction block, the second stage of grouting (known as JOG, Tateyama and Arima) is conducted in which quick setting grout is injected into silty sand layer right under mat foundation between GL-7m to GL-9m in Fig.1 to jack and level this building. The location of JOG grouting tube is 20cm offset from TAM tube. The layout of 35 grout holes is shown in Fig.2.

To improve the grouting efficiency, the simultaneous injection of extremely short gel time grouts from as many as grouting holes is required (Soga et al., 2004). An automatic injection system of 18 grouting tubes and a central controlling unit in Fig. 3 is used. The grouting duration at each grouting tube and grouting order of each cycle monitored by a central processing computer is scheduled each day based on the daily monitoring results of column elevation. Each grouting tube is connected to an on-off switch valve activated by compressed air pressure corresponding to the instruction from central processing computer as shown in Fig. 4.

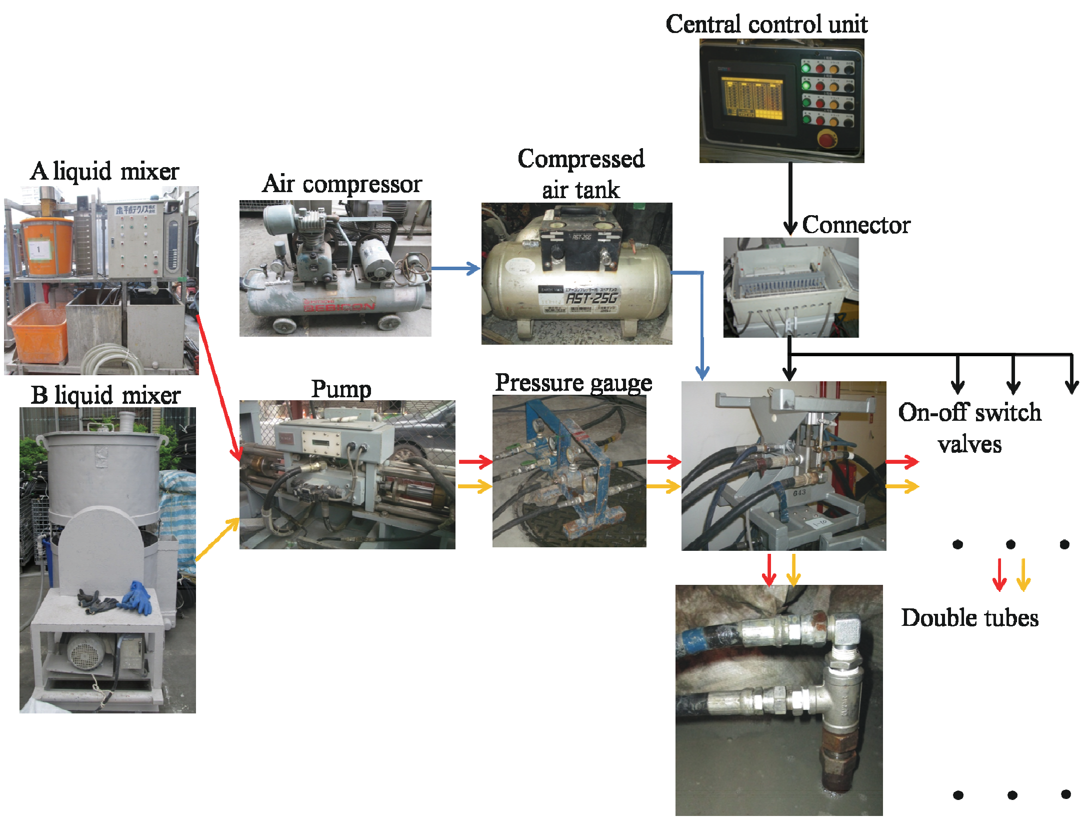

FIG.3. Automatic injection system and central controlling unit

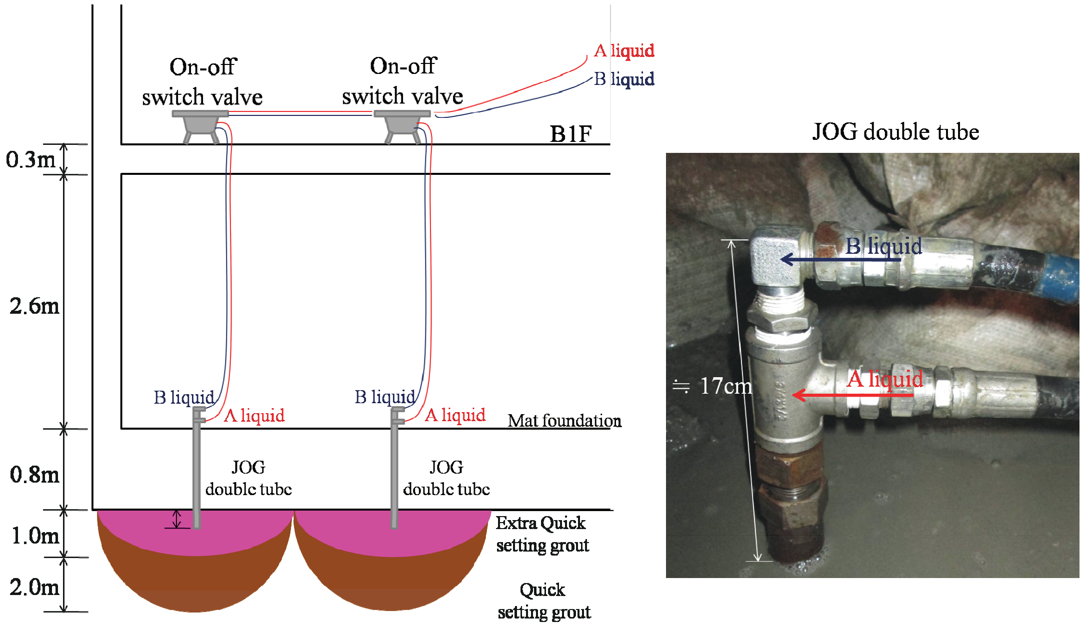

FIG.4. Two shot grouting system with flash and quick setting grouts

The double tube (Fig. 4) is employed to inject grouts of extremely short gel time (Table 2), in order to prevent premature solidification and limit the travel of cement grout. In this case, two types of grouts are injected separately and are mixed and solidified at the outlet of the tube.

Table 2. Grout mix of 2s gel time grout

A liquid (200 liters)		B liquid (200 liters)	
PR silica (liters)	56.7	**Cement (kg)**	100 ± 25
SG hardener (liters)	11.0	**Permarock (kg)**	12.5 ± 2.5
Water (liters)	132.3	**PR actor (kg)**	5 ± 2
		Water (kg)	160

It is possible to select the grouting mode by varying the cycle time defined by the summation of injection time for each hole in the multiple holes injection system. For example, when the cycle time is shorter than the gel time, the grout will penetrate through the yet-to-be hardened zone from previous injection to create a reaction zone. On the other hand, when the cycle time is longer than the gel time, the grout is repeatedly injected into within the zone where the grout from previous injection has already been hardened. Thus, this will effectively limit the travel of grout outside the zone, and this will initiate the heave of ground and the building above.

MONITORING SYSTEM AND GROUTING PERFORMANCE

The elevations at seven columns outside of building (SB-1 to SB-7 in Fig. 2) were monitored using laser level before and after each day grouting. Fig.5 shows the relationship between grout take and column elevation change. The building's southwest corner at SB-7 is raised by 15.55 centimeters and the elevation at SB-3 remains almost unchanged, and this fact reflects the grout take distribution plan. The elevation change contour lines of mat foundation are also generated from the elevation change monitoring results on a daily basis. The volume between mat foundation contour lines before grouting and mat foundation contour lines after grouting is the elevated volume of the inclined building at the end of each day. The volume between mat foundation contour lines after grouting and mat foundation contour lines before next day grouting is the building's settled volume overnight due to the dissipation of excess pore pressure from previous grouting. During the second stage of grouting, the accumulative daily injected grout take, elevated and settled volumes of building in bar chart and total elevated and settled efficiencies in curve are shown in Fig.6. From day one, the elevated volumes are bigger than the settled volumes for every grouting day. This is benefit from the first stage of grouting creating a stronger reaction foundation. Otherwise the re-settlement will override the previous heave (Wongsaroj et al., 2007, Ni and Cheng, 2009, Ni and Cheng, 2010). The total grout takes of 134 m^3, total elevated volume of 35.72 m^3, and total settled volume of 3.94 m^3 are recorded at the end of second stage grouting. The final elevated efficiency of 23.72 % is obtained by subtracting settled volume of 2.94 % from the elevated volume of 26.66 % as shown in Fig.5. This building was inclined southwest at an angle of 1/68 and is restored to near level at an angle of 1/328 in 12 days for second stage grouting.

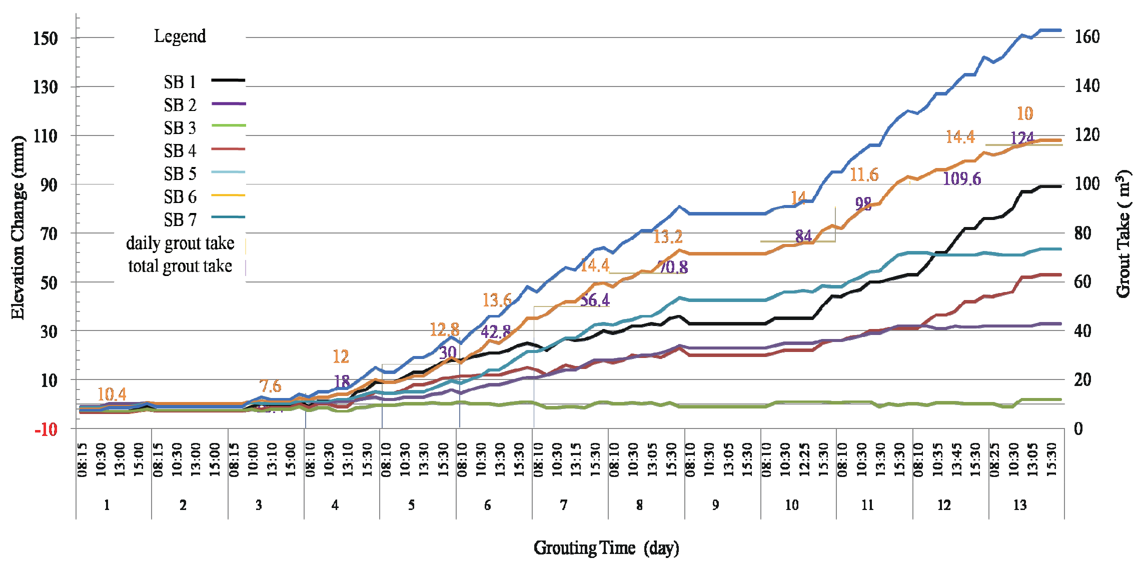

FIG.5. The relationship between grout take and column elevation change

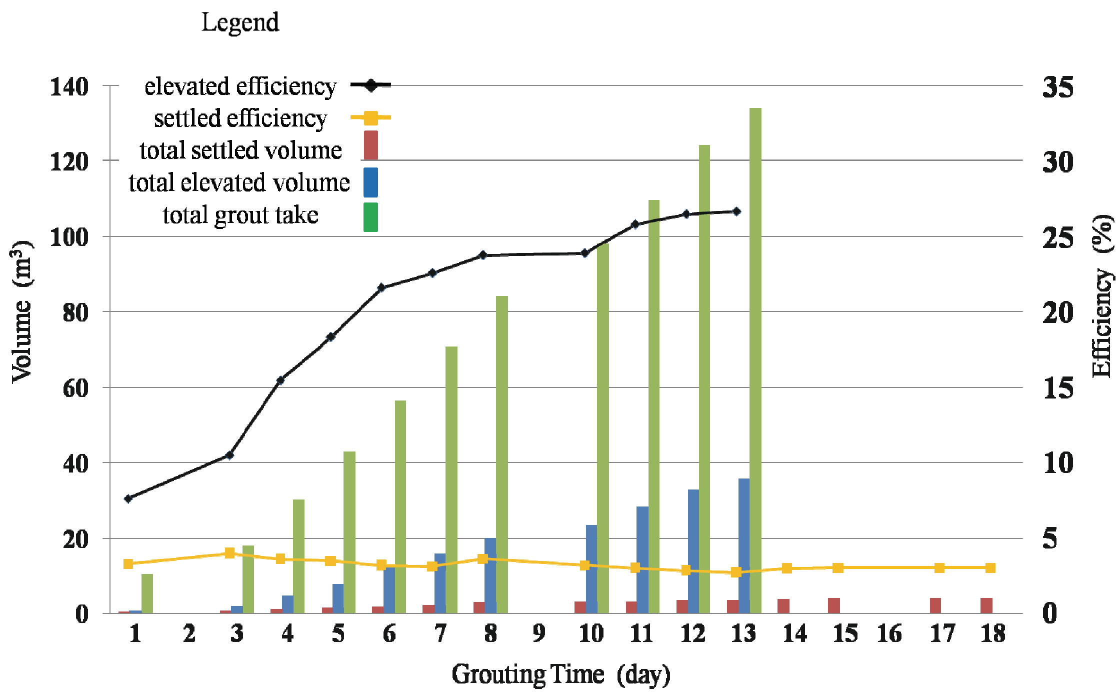

FIG.6. History of total grout take, elevated and settled volumes, and grouting Efficiency

CONCLUSIONS

This building inclined southwest at an angle of 1/68 is restored to an angle of 1/328 after two stages of grouting. The first stage of grouting is used to change soft clayey foundation into firm reaction zone by injection through 35 grouting tubes with 15 sleeves each. The cementious grout of 507.9m^3 for the first stage is injected in 40 days. During the second stage of grouting, a multiple injection system controlled by a computer to define the grouting order and duration is used to inject very quick setting grouts of 134m^3 through double tubes to level the building for good in 12 days.

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REFERENCES

Au , S.K.A. , Soga , K. , Jafari , M.R. , Bolton , M.D. & Komiya , K. (2003) , Factors affecting long-term efficiency of compensation grouting in clays. Journal of Geotechnical and Geoenvironmental Engineering , 254-262.

Komiya , K. , Soga , K. , Akagi , H. , M.R. & Bolton, M.D. (2001). Soil consolidation associated with grouting during shield tunneling in soft clayey ground. Geotechnique 51 , No.10 , 835-846.

Ni, James C. and Cheng, Wen-Chieh (2010). Monitoring and modeling grout efficiency of lifting structure in soft clay. International Journal of Geomechanics, Volume 10, Issue 6, pp. 223-229, ISSN: 1532-3641。

Ni, James C. and Cheng, Wen-Chieh (2010). Using fracture grouting to lift structure in clayey sand. Journal of Zhejiang University SCIENCE – A, Volume 11, No.11, pp. 879-886。

Ni, James C. and Cheng, Wen-Chieh (2010) Fracture grouting to lift structure in clayey sand. The Art of Foundation Engineering Practice: A Geotechnical Special Publication Honoring Clyde Baker, Geotechnical Special Publication No. 198, American Society of Civil Engineers, pp. 470-485, ISBN 978-0-7844-1093-4。

Ni, James C. and Cheng, Wen-Chieh (2009). The Grout Efficiency of Leveling Building on Very Soft Clay. Geotechnical Special Publication No.194: Soils and Rock Instrumentation, Behavior and Modeling, p.1-p.8, ISBN 978-0-7844- 1046-2。

Soga , K. , Au , S.K.A. , Jafari , M.R. & Bolton, M.D.(2004). Laboratory investigation of multiple grout injections into clay. Geotechnique 54, No.2 , 81-90.

Tateyama, Kazuyoshi and Arima, Shigeharu. Repair Technology for Tilted Structures by Grouting, Technological Report.

Wongsaroj , J. , Soga , K. & Main , R.J. (2007). Modelling of long-term ground response to tunneling under St. James's Park, London. Geotechnique 57, No.1 , 75-90.

Verification of Design Criteria for Bridge Approach Slabs

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ABSTRACT

Approach slabs are used in bridges to reduce the differential settlement between the bridge abutment and the approaching road pavement. In ideal conditions the approach slab is simply supported at the abutment and cast on a uniform, well-compacted surface. In reality compaction specifications under an approach slab are not fully achieved due to the difficulty of compacting in a restricted area. A very conservative method of designing an approach slab would be to assume that the fill underneath provides no elastic support to the approach slab, and to design the slab as simply supported over the entire length. Most codes and design guides take into account that the fill underneath the slab provides a varying degree of support to the approach slab, and require the designer to use an effective span factor. South African (TMH7 and SANRAL) design codes and guidelines give very general design criteria for the design of an approach slab with no consideration for site specific conditions. SANRAL recommends an effective span factor of 0.67 in the "Code of procedure for the planning and design of highways and road structures in South Africa". This paper considers the influence of varying elastic support conditions on the effective span of an approach slab. Different support conditions are investigated, varying from well compacted to poorly compacted and the recommended 'rule of thumb' given in the SANRAL design guide is assessed.

INTRODUCTION

Approach slabs are used as a link between a bridge abutment and the approaching road pavement. Without an approach slab differential settlement of the road pavement and the bridge structure can result in dip or "bump" in the road before and after the bridge. This differential settlement is due to fact that the abutment of a bridge and is normally founded on competent bedrock resulting in very limited settlement, and the road pavement is support on a more flexible substructure, resulting in comparatively more settlement.

Thiagarajan et al., 2010 states that the purpose of an approach slab is to provide a smooth transition between pavement and bridge by minimising the effects of the differential settlement. The effectiveness of an approach slab is influenced by the soil-structure interaction. Geotechnical factors that influence approach slab behaviour are approach fill settlement; inadequate compaction of embankment fill; poor drainage; and erosion of fill material forming a void under slab. Structural factors include approach slab thickness and amount and placement of reinforcement.

To date there are no reported or adopted rational design procedures for bridge approach slabs in spite of their extensive usage. In South Africa many bridge engineers don't give much thought to the design of approach slabs and use 'rules of thumb' and standard details when specifying and detailing them.

CURRENT DESIGN STANDARDS IN SOUTH AFRICA

The design code for bridges in South Africa is TMH7 (1989), which has no design guides for the structural design of approach slabs considering differential settlement. The only reference to approach slabs in the TMH7 (1989) refers to its effect on the design of the abutment – if an approach slab is provided at the abutment no traffic load surcharge need to be considered on the upper part of the wall equal to a height of two-thirds the length of the approach slab. To keep calculations simple bridge designers often ignore the soil support under the approach slab and design it as a simply supported slab subjected to the live loads that the deck is designed for. This method is very conservative, but does allow for the possibility that the retained materials behind the abutment may become saturated or washed away, which is a design consideration required in TMH7 (1989). A more efficient design would consider the effect of the elastic support provided by the soil beneath the approach slab.

In 2002 the South African National Roads Agency (SANRAL 2002) developed guidelines for designing and specifying approach slabs in South Africa, where most approach slabs are buried under base course of the pavement layer:

- Approach slabs are required for all bridges with abutments exceeding 4m in height
- The minimum length of an approach slab is 3m. Where abutments are rigidly supported and the fill is compressible a longer approach slabs is required. The length of the approach slab should equal the expected differentiable settlement multiplied by a factor of 200. A gradient of 1/200 is considered acceptable.
- The slabs shall be designed to carry the live loads specified for the deck with effective span of 67% of the approach slab length.
- Reinforcement is to be provided in the bottom of the slab only.

From the above it is clear that a verification of the "rules of thumb" effective span for approach slab design is necessary. Experimental work has been done in this paper in order to access the effective span value given in SANRAL's design guide.

EXPERMENTAL WORK

In order to access the effect of varying compaction under an approach slab a representative reinforced concrete strip was tested with a moving 300mm x 300mm wheel or patch load, supported with varying levels of compaction simulated with springs of different stiffness. Two different springs were used for support. The spring stiffness and modulus of subgrade reaction calculated for each springs supporting a 300mm x 300mm area is shown in Table 1. The 190 dia x 38mm springs are roughly half as stiff as the 150 dia x 38mm springs and therefore these springs were used to represent the soil that has not been compacted as effectively behind the abutment.

Table 1. Spring stiffness

Spring		Spring stiffness	Modulus of subgrade reaction
150 dia x 38mm	Stiff	4000kN/m	44 400 kN/m^3
190 dia x 38mm	Soft	2500kN/m	27 700 kN/m^3

A 300-mm wide, 100-mm deep, 1500mm long concrete strip with nominal reinforcement was loaded with a moving 40kN patch load (representative axle load) and the defection at the centre of each spring along the strip at the maximum load was recorded. This deflected shape was then used to calculate an effective deflection, which was used to calculate an effective simply supported span using properties shown in Table 2.

Table 2. Test parameters

Item	Description
28 day Concrete strength (f_{cu})	39.52MPa
Concrete E-modulus (E)	30.7GPa
Width of beam	300mm
Depth of beam	100mm
Length of beam (L)	1500mm
High tensile Reinforcement	Y10@200 Mesh
Cracked moment of inertia ($I_{cracked}$)	4593897 mm^4
Cover (c)	15mm
Spacing of springs	300mm
Representative axle load (P)	40kN

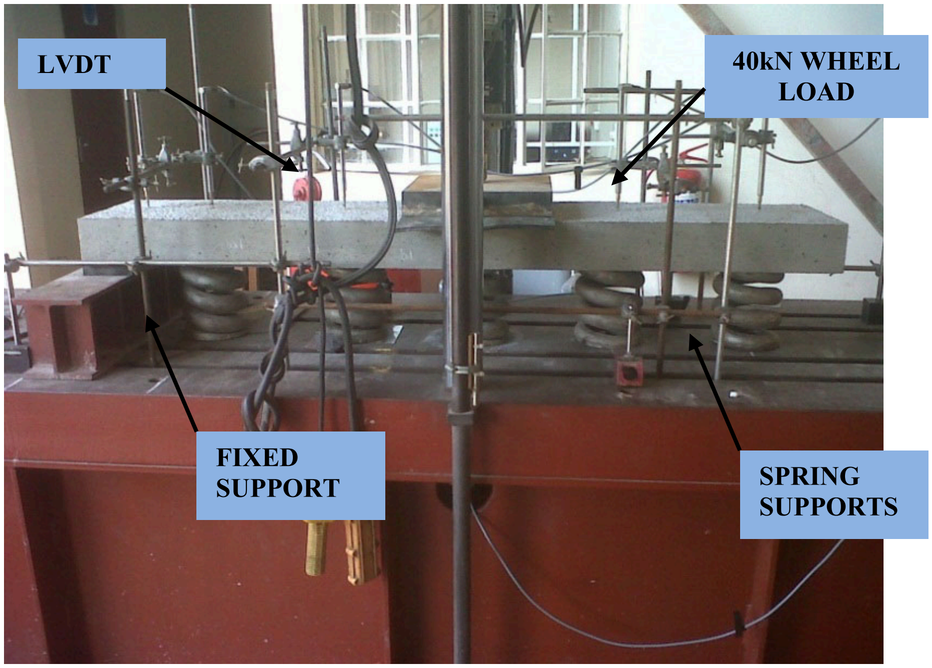

Figure 1. Experiment set up showing springs and LVDT's (Glitz 2012)

From a test setup deflections at the centre of each spring were logged with LDVT's as the load was applied. The calculation of the effective length factor for a typical loading and support condition (B3) is shown in Figure 2 below.

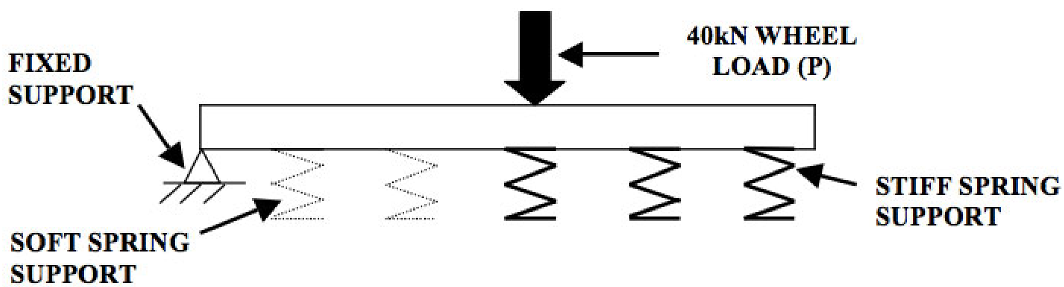

Figure 2. Typical test set up

A deflected shape at maximum load was drawn and the effective deflection (δ_{eff}) determined as shown in Figure 3. A straight line was drawn between the sample's end points. The length of a vertical line from the point of maximum deflection to the straight line gives the effective deflection.