as 23.83% when lime is added by 3% with the series-2 of mixed soil, in where the proportion of RHA, pond ash and soil are remained as 40%, 40% and 20% respectively.

However from the FIG. 4, significant performance has been observed for soaked CBR value of the tested soil when mixed with pond ash, rice husk ash and lime. The soaked CBR of tested soil is 4.9% and with the increasing amount of pond ash and decreasing amount of soil these values increases to 10.12%, 12.52% and 8.36% for the ratio of soil, pond ash and rice husk ash as 60:20:20, 40:40:20 and 20:60:20 respectively without mixing of lime. Further when these mixed soil added with the increasing amount of lime from 1% to 3%, this value increases in all the cases. But significant observation is made when lime is added by 3% with the series-2 of mixed soil and this value becomes 17.46% for the proportion of RHA, pond ash and soil are remained as 40%, 40% and 20% respectively. This value is nearly four times the corresponding value of the virgin soil.

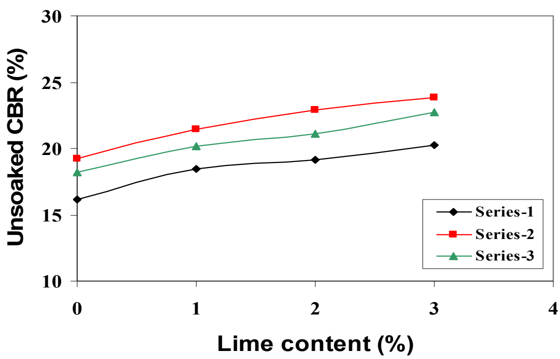

FIG. 3. Variation of CBR (unsoaked) of Pond ash and Rice husk ash mixed alluvial soil with varying percentage of Lime

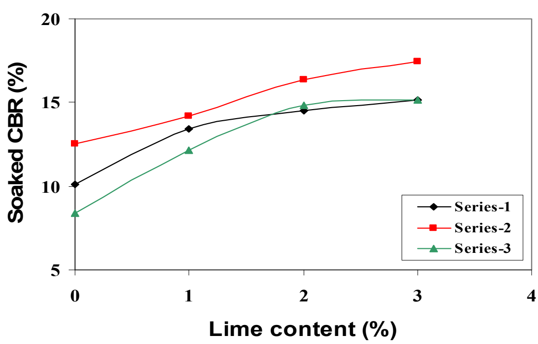

FIG. 4. Variation of CBR (soaked) of Pond ash and Rice husk ash mixed alluvial soil with varying percentage of Lime

CONCLUSION

From this experimental study, the following conclusions can be made:

1. Consumption of waste materials like pond ash and rice husk ash in bulk quantity in the construction of road project can be made with reducing the accumulation hazard and environmental pollution.
2. Addition of rice husk ash in increasing proportion with the alluvial soil decreases the maximum dry density of the mixed soil with or without mixing of lime due lower dry density of pond ash and rice husk ash. However the optimum moisture content of the mixed soil increases gradually with the increased percentage of pond ash, rice husk ash and lime due to higher demand of water of pond ash and rice hush ash for achieving maximum density compared to the virgin soil.
3. In strength characteristics, CBR value in soaked and unsoaked condition increases gradually for addition of increasing amount of pond ash and rice husk ash with alluvial soil. However addition of lime in increasing proportions with these mixed soils show the better increment in the CBR values both in the soaked and unsoaked conditions. Significant CBR value is observed for the local alluvial soil mixed with 40% pond ash, 20% rice husk ash and 3% lime, and the said value in unsoaked condition is nearly 2 times and in soaked condition is 4 times the corresponding value of the virgin soil. Such an increase seems due to greater pozzolanic action of pond ash and RHA with lime in presence of water.

REFERENCES

Ali, M.; and Sreenivasulu, V. (2004), "An Experimental Study on the Influence of Rice Husk Ash and Lime on Properties of Bentonite." *Proceedings of the Indian Geotechnical Conference,* Vol. I: 468-471.

Bhasin N.K, Goswami N.K., Oli P., Krishan N., Lal N.B. (1985) Utilization of waste material in construction of roads in rural areas." *Seminar on road and Road Transport in Rural area,CRRI, New Delhi* : 260-267.

Chandra, S., Kumar, S. and Anand, K. R., (2005) "Soil Stabilization with Rice Husk Ash and Lime Sludge." *Journal of Indian Highway, Indian Road Congress, (May)*: 87-98.

Ghosh, A., and Subbarao, C., (1998) "Hydraulic Conductivity and Leachate Characteristics of Stabilized Fly Ash." *Journal of Environmental Engineering, ASCE,* Vol.124, No.9, September: 812-820.

http://www.worldbank.org/html/dec/Publications/Abstracts97/03esd/esd22.html

IS 2720. Method of Test for Soil (Part ∇III) (1980) Laboratory Determination of Moisture Content & Dry Density.

IS 2720. Method of Test for Soil (Part X∇I) Laboratory Determination of CBR.

Rao A.V.N., (1999). "Characteristics of Fly ash its applications – A brief review." *Proceedings`of the national seminar on Fly ash characterization and its Geotechnical applications, Fly ash Mission, TIFAC, Bangalore*: 1-8.

Sublayer Strength Evaluation with FWD in Semi-rigid Base Asphalt Pavement Rehabilitation Project

Lin CONG[1], Robert L Lytton[2], Zhaoxing XIE [1]

[1]Associate Professor, Key Laboratory of Road and Traffic Engineering of MOE, Tongji University, Shanghai, 201804, P.R. China, conglin@tongji.edu.cn
[2]Professor, Department of Civil Engineering, Texas A&M University, College Station, TX, 77843-3136, USA, r-lytton@civil.tamu.edu
[3]Engineer, Shanghai Municipal Planning Design and Research Institute, 609 Jianguoxi Road, Shanghai 200031, P.R. China, xzx9898@163.com

ABSTRACT: This paper used dynamic FEM model instead of continuum elastic layered system to simulate whole or broken semi-rigid base asphalt pavement response under FWD. Calculating results indicated that the sublayer strength can be evaluated by special FWD deflection basin parameter. Subgrade modulus (Esg) can be well evaluated by Curvature Index CI_7 and Shape Factor F_8 and the estimated results were not affected by pavement structure cracking condition. Whether Esg greater than 170MPa or not is defined as pavement subgrade failure criteria. Curvature Index CI_3 can use to indicate the semi-rigid base layer structural condition and its criteria is CI_3 value greater than 60um. This method have been applied and validated successfully in Jialiu Expressway rehabilitation project in Shanghai. It can more precisely distinguish weak sections for pavement rehabilitation design.

INTRODUCTION

After more than ten years continuing development, a large part of expressway pavements in China that mostly were semi-rigid base asphalt pavement type has stepped into rehabilitation phase. All the semi-rigid bases were made of lime and fly-ash stabilized aggregate or cement stabilized aggregate. These pavement structure rehabilitation projects require to divide the whole road into analysis sections by structural bearing capacity, service condition, etc, especially base layer structural condition and subgrade strength. One analysis section has one representative evaluation result used in design procedure. In China highway agencies used to using Benkelman Beam deflection data to analyze pavement strength and divide road section. But the B-B surface deflection reflects the full-depth pavement bearing capacity, but it can not show the base layer and subgrade condition, which impair designer making correct rehabilitation practice.

To date, Nondestructive testing (NDT) is widely recognized as an important tool for pavement structural evaluation. Falling weight deflectometer (FWD) has gained acceptance as the most developed pavement structural testing device for its ability to apply heavy load and to simulate actual truck traffic wheel loading. Currently, a number of FWD backcalculation programs can estimate each layer modulus by modeling pavement as linear or nonlinear elastic system; these moduli are then used to compute the effective pavement structural capacity.

Actually, these semi-rigid base asphalt pavement in rehabilitation phase usually has been broken by cracking, interface sliding, so using continuum elastic layer system model to will cause unreasonable backcalculation moduli results. AASHTO(1993) suggests not to calculate existing pavement structural number (SN_{eff}) using inverse effective moduli of each layer in pavement rehabilitation evaluation. Uddin, Z. Pan found that broken or distressed pavement causes backcalculated moduli's difference, and developed new revised backcalculation software. Yusuf Mehta found that pavement structure condition such as layer broken, depth, and temperature variation effected deflection bowl shape more than the inverse moduli. Cong Lin demonstrated distressed and broken semi-rigid base pavement generates anomalistic deflection bowl under FWD load, which diminishes the usefulness of traditional backcalculation methods. Friedrich W.J. described a fast computer program (PROBE) that calculates important mechanistic response parameters and determines the quality of data and the degree of structural integrity of the pavement layers under whole or broken conditions. For this reason, the new approach should be adopted to interpret FWD data in order to evaluation the sublayer structure condition of semi-rigid base asphalt pavement.

OBJECTIVE

1. Build the dynamic hypothesis FEM model of whole and broken or cracked semi-rigid base asphalt pavement.
2. Using systematic statistic regression analysis, study the deflection bowl index to interpret the degree of structural integrity of the semi-rigid base layer and quality of soil subgrade strength and set up the base layer and subgrade strength failure criteria.
3. Apply and validate the new method through practical project.

WHOLE AND BROKEN PAVEMENT FEM MODEL

The FWD load is assumed as 0.7Mpa peak haversine impulse load in 30ms duration time and distributing over a circular contact pressure area 15cm in radius. According the field semi-rigid base asphalt pavement distressed condition survey, transverse cracking, longitudinal cracking and block cracking is the main distressed type. The pavement FEM models simulate the whole integrity structure and distress structures considering different cracking types, position, depth, extension and tensity.

In order to set up a reasonable deflection data ware, a series of semi-rigid base pavement structure combinations and materials properties is considered as Table 1. Assembling all above factors by random, 11808 pieces of pavement model were got finally. It took half a year to calculate all the FEM models to generate the deflection data ware.

Table.1 Parameters for Semi-Rigid Base Asphalt Pavement FEM Model

Parameter	AC layer	Base layer	Subbase layer	Subgrade
Thickness (cm)	9, 12, 15, 18, 21	20, 30, 40	15, 20, 30, 40	Infinity
Modulus（GPa）	1, 2, 4, 7, 11	1, 3, 6, 9, 20	0.4, 2, 4, 7, 13	0.035, 0.1, 0.2, 0.35
Density（kg/m^3）	2400	2200	2100	1800
Poisson's Ratio	0.30	0.25	0.25	0.30
Damping (%)	5	5	5	5

Five types of deflection bowl shape indexes were used to obtain the layer modulus and structure integrity condition through systematically statistic regression software SPSS, including: direct deflection; curvature Index; Shape Factor; Slope index; Area index.

SUB-GRADE SOIL MODULUS CALCULATION AND FAILURE CRITERIA

From the above extensively deflection systematically statistic analysis results, it was found that among all the five types deflection indexes, combination of Curvature Index CI_7 and Shape factor F_8 can uniquely determine the subgrade modulus, seeing Figure 1. Essentially, this statistic relationship was regressed from all the whole and broken semi-rigid base asphalt pavements, so it was also effective for the severely cracked and broken pavement evaluation in rehabilitation projects. The definition of CI_7 and F_8 is as follow:

$$CI_7 = d_7 - d_8 \quad (1)$$

$$F_8 = \frac{d_7 - d_9}{d_8} \quad (2)$$

Where: d_7、d_8、d_9 respectively are surface deflection of Number7, 8, 9 geophone of FWD, μm.

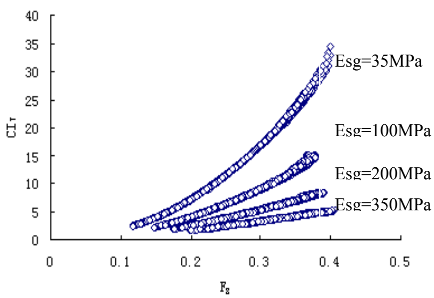

FIG.1. Relationships among CI_7,F_8,and subgrade modulus Esg

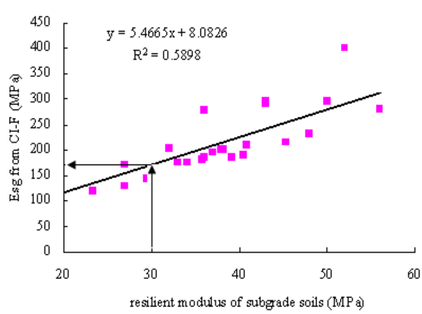

FIG.2. Relationship between Esg of FWD and static resilient modulus

In Huning Expressway rebuilding project and Jialiu Expressway rehabilitation project both in Shanghai, FWD deflection, Bearing Plate and Benkelman Beam deflection were well planned and measured on the whole and severely cracked pavement section. The

FWD was tested on the pavement surface, and at the same position the other tests were carried out on the subgrade surface right after the upper layer dismantled. By this way, for the same subgrade position dynamic modulus was calculated from FWD testing deflections using CI_7 and F_8 relationship; correspondingly, the static resilient modulus was calculated from the Bearing Plate and Benkelman Beam deflection testing data using standard method. The final calculation results were shown in FIG 2. the fine relationship between them demonstrates that the FWD sub-grade modulus calculation method is reasonable.

In asphalt pavement design specification of china, the static resilient modulus of subgrade soil is specified as no less than 30Mpa for high grade asphalt pavement. So according to the relationship between dynamic modulus back calculated Esg of FWD and static resilient modulus measured by bearing plate testing, Esg above the minimum limit 170MPa is defined as the expressway asphalt pavement's sub-grade failure criteria, shown as in Fig 2.

BASE LAYER BROKEN CONDITION DISCRIMINATION CRITERIA

Semi-rigid base layer contributes the large part bearing capacity of asphalt pavement, cracks and broken is its main deterioration types, so judging the base layer broken or not by NDT is the premise to determine whether to replace it in rehabilitation project. The above deflection data ware statistic regression shows that CI_3 is the most sensitive index to the base modulus and broken condition.

$$CI_3 = d_3 - d_4 \tag{3}$$

Where: d_3, d_4 are surface deflection of Number3, 4 geophone of FWD, respectively.

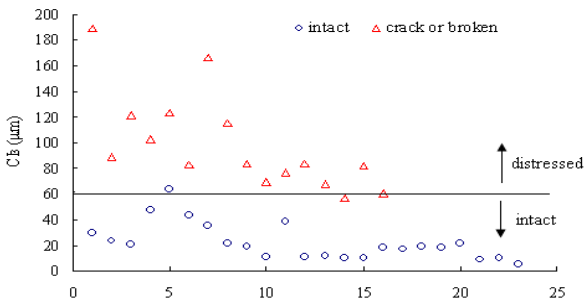

FIG.3. Intact and broken semi-rigid base layer comparison by CI_3 index.

This project chose a new expressway semi-rigid base asphalt pavement in Shanxi Province to test deflection basin by FWD, so its CI_3 results certainly reflected the whole intact base layer structure condition. Correspondingly, the same type pavement structure in Jialiu expressway rehabilitation project in Shanghai was tested by FWD. After surface deflection testing, surface asphalt layer was wiped out and semi-rigid base layer was well checked by experienced engineers by walk to find the cracked and distressed position in the semi-rigid base layer, these positions were screened on its surface deflection. Totally, there were 23 effective testing points (listed on X-axis). By this way, it can get the relationship between CI_3 index and structural condition of the semi-rigid base layer. Both of the CI_3 index final result is shown in FIG 3.

Obviously, base layer in a distressed and broken condition, its CI_3 will increase over 60um, so this 60um CI_3 divining line is suggested to be the semi-rigid base layer broken condition discrimination criteria. Although there were 3 points not according with the law, this criterion can be accepted considering the complexity of field testing.

APPLICATION OF THE SUBLAYER STRENGTH EVALUATION METHOD

In May 2008, one 2 Km long road segment was tested by FWD in Jialiu Expressway to apply and verify the sublayer strength evaluation method to distinguish the failure or weak semi-rigid base asphalt pavement section. The deflections of nine geophones of total 35 points were drawn in Fig 4.

Using above relationship functions to calculate all of the subgrade soil dynamic modulus Esg and semi-rigid base layer CI_3, the results were shown in Fig 5 and Fig 6.

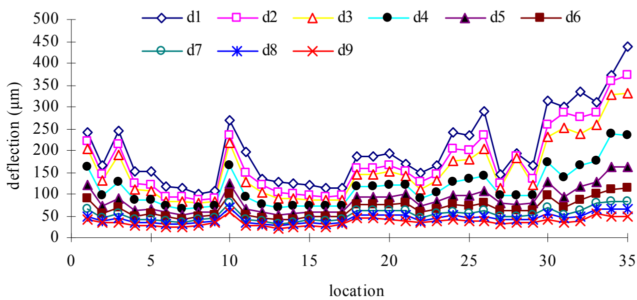

FIG.4. Intact and broken semi-rigid base layer condition comparison by CI_3 index

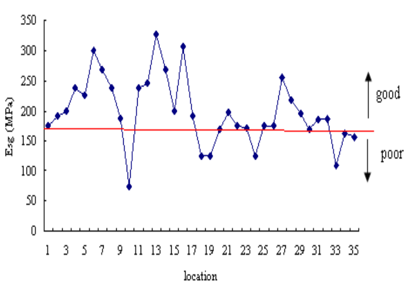

FIG.5. E_{sg} ranging in the tested segment

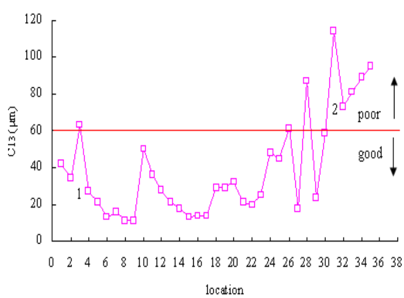

FIG.6. CI_3 index ranging in the tested segment

After milling out the surface asphalt layer, core the base layer at point 4 and 33, marking 1 and 2 in Fig6. The coring specimen showed that base layer at point 4 was well and integrity, but the base was broken and loose at point 33 even not to get one integrity core. These was consistent with judgment result by CI_3 that base layer at point 33 was poor and broken. The Esg values from point 18 to point 35 in Fig 5 were almost below 170MPa, so the segment can be distinguished as poor subgrade section. In Fig 6, the base layer section from point 26 to point 35 was in broken condition. Finally in the rehabilitation practice, the section between points 24 to point 35 was designed to mill out asphalt layer and base layer, improve subgrade strength by mixing lime and compaction, and then rebuild the cement-treated base layer. This project got a satisfied appraise from all the attendant parts.

CONCLUSIONS

The investigations carried out have been particularly concerned with expressway rehabilitation project in Shanghai. This study has led to the following conclusions:

1. For the severely cracked and broken semi-rigid base asphalt pavement, it can not use FWD deflection bowl to estimate sublayer structural condition effectively for the rehabilitation project by backcalculation program based on the continuum elastic layer system.
2. Combination of Curvature Index CI_7 and Shape factor F_8 can uniquely determine the subgrade modulus even in the severely cracked and broken pavement condition. Whether Esg larger than 170MPa or not is defined as pavement subgrade failure criteria.
3. Curvature Index CI_3 can well indicate the semi-rigid base layer structural condition, the value 60um of CI_3 is suggested to be the semi-rigid base layer broken condition discrimination criteria.

Finally, due to space limitations, only the major parts are highlighted herein. The methods have been successfully applied in Jialiu Expressway rehabilitation project in Shanghai. Moreover further validation studies are ongoing in other practical projects.

REFERENCES

AASHTO. (1993). “AASHTO Guide For Design of Pavement Structures.” American Association of State Highway and Transportation Officials, Washington.

Cong Lin and Z.Y. Guo. (2006) “Analysis and Evaluation of Transverse-Cracked Semi-Rigid-Base Asphalt Pavements Using FWD Data.” *ASCE Geotechnical Special Publication*.

Friedrich W. Jung and Dieter F.E. Stolle. (1992). “Nondestructive testing with falling weight deflection on whole and broken asphalt concrete pavements.” *Transportation research record*, No.1377.

Lee, Y. (1997). “Condition Assessment of Flexible Pavements Using FWD Deflections.” Ph.D. thesis. North Carolina State University, Raleigh.

Uddin, W. and Pan, Z. (1997). “Finite Element Dynamic Analysis of Distress Asphalt Pavements.” *the 8th International Conference on Asphalt Pavements*, Washington.

Mehta, Y. and Roque, R. (2003). “Evaluation of FWD Data for Determination of Layer Moduli of Pavements.” *Journal of Materials in Civil Engineering*. Vol. 15, No. 1, January/February 2003, pp. 25-31.

Evaluation of Subgrade Modulus for Semi-Rigid Asphalt Pavement Using Deflection Basin Parameter

Zhaoxing Xie[1,2], Lin Cong[2], and Zhongyin Guo[3]

[1] Key Laboratory of Shanghai Road Engineering, Shanghai Municipal Planning Design and Research Institute, 609 Jianguoxi Road, Shanghai 200031, P.R. China;email::xzx9898@163.com
[2] Corresponding author. Key Laboratory of Road and Traffic Engineering of MOE,Tongji University, 4800 Caoan Road, Shanghai 201804,P.R. China; email: tjconglin@163.com
[3] Key Laboratory of Road and Traffic Engineering of MOE,Tongji University, 4800 Caoan Road, Shanghai 201804,P.R. China; email: zhongyin@tongji.edu.cn

ABSTRACT: The paper presents a method based on deflection basin parameters to evaluate the subgrade modulus. The paper develops 2-D and 3-D dynamic FEM to simulate semi-rigid asphalt pavement deflection basin response under FWD loading pulse. It is discovered that the relationship between Curvature Index CI_6 and Shape Factor F_6 may be used to determine the subgrade modulus. The moduli, thicknesses and cracked condition of upper layers have minimal effect on the relationship between CI_6 and F_6. Based on the calculation and analysis, the nomograph of subgrade modulus is presented.

INTRODUCTION

The Falling Weight Deflectometer (FWD) is an excellent device for evaluating the pavement structural. Most of the backcalculation programs which have been used to estimate moduli of pavement layers employ the static analysis as a forward model. Chang et al. (1992) concluded that static analysis-based programs often underestimate the subgrade modulus when deflections obtained from dynamic tests are used. Lee (1997) and Kim (2001) proposed the backcalculation procedures that incorporated the dynamic effect to assess the subgrade condition. However, the scope of their study is limited to full-depth asphalt pavement and aggregate base asphalt pavement. The semi-rigid base asphalt pavement (a pavement with semi- rigid material as base course and subbase course, such as cement-stabilized or lime fly-ash stabilized material) is one of major structural forms of asphalt pavement in China, and the performance and the state of stress of semi-rigid base asphalt pavement are quite different from full-depth asphalt pavement and aggregate base asphalt pavement. Thus, in the paper a backcalculation method to determine the subgrade modulus by deflection basin parameters is investigated for semi-rigid base asphalt pavement.

Pavement Model and Model Parameters

The 2-D FEM and 3-D FEM of semi-rigid base asphalt pavement are developed on the basis of ANSYS. The lengths of 2-D axi-symmetric FEM model are set to 8 m. The size of 3-D FEM model is 8m×8m×8 m. The nodal points at the bottom boundary are fixed whereas those on the vertical boundary are constrained from moving in the horizontal direction. The FEM mesh is designed finer at the loading area. At locations father from the load, the mesh becomes coarser to reduce the computation burden. For intact pavements when the load is away from the edges, a 2-D finite element model is proved to yield results suitable for the traffic loading analysis (Cho et al. 1996). However, transverse or longitudinal cracks can not be modeled using 2-D axi-symmetric finite elements since cracks do not occur in a circular shape (Lee 1997). Thus, in this paper the 2-D FEM model is employed for the intact pavements, and the 3-D FEM model is used to model pavement with transverse cracks.

Semi-Rigid base asphalt pavement is considered as a four-layered system with linear elastic material properties. It is known that soils are stress-state dependent materials. Because of the time limitations of the study, the stress-state dependent behavior will not be studied in the paper. The pavement layer properties are given in table 1. A half-sine load with 50KN peak load and duration of 0.03 s that simulates a typical FWD load is used for dynamic analysis. The deflection sensors are placed at distances of 0, 200, 300, 600, 900, 1200, 1500, 1800, and 2100 mm from the loading center. Because the use of transient data is too complicated, only peak deflections obtained from transient data are utilized in this study. The dynamic analysis shown that the effect of the stiff layer depth to the surface deflections vanishes when the depth of the stiff layer is greater than (or equal to) 6.0 m. Therefore, the 2-D and 3-D finite element model in this study could be considered semi-infinite when dynamic analysis is employed.

Table 1. Parameters for Semi-Rigid Base Asphalt Pavement

	AC layer	**Base layer**	**Subbase layer**	**Subgrade**
Modulus(MPa)	1000, 2000, 4000, 7000, 11000	1000, 3000, 6000, 9000, 20000	400, 2000, 4000, 7000, 13000	35, 100, 200, 350
Thickness (cm)	9, 12, 15, 18, 21	20, 30, 40	15, 20, 30, 40	Infinity
Density(kg/m^3)	2400	2200	2100	1800
Poisson's Ratio	0.30	0.25	0.25	0.30
Damping (%)	5	5	5	5

The single reflection crack is one of main distressed types for semi-rigid base asphalt pavement. Therefore, the single reflection crack is considered in this study and the computed deflections from cracked pavements will be compared against those of intact pavements to develop the subgrade strength evaluation method. Figure 1 presents the crack conditions in this study. The single reflection crack perforates both