Theoretical Study of Bonding Condition at the Interface between Asphalt Pavement Layers

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Abstract: This paper presents the theoretical study of influence of bonding condition between asphalt pavement layer on pavement structural responses based on the theoretical assumption and software based analysis. The bonding condition in this analysis are range from weak bonding to strong bonding which represent the partial bonding conditon as a realistic condition at interface between pavement layers. The standard shear spring compliance in BISAR software is used to represent this bonding condition. Applying the horizontal forces and reducing surface layer are also described. The results indicate that the better bonding condition at the interface between layers will decrease the strain responses. Hence, better structural capacity can be achieved with better bonding between layers.

Keywords: Pavement Bonding, Shear Reaction Modulus, Standard Shear Spring Compliance

1. INTRODUCTION

As a country which consists of thousands island, transportation aspect is very serious problem in Indonesia. Transportation cost is a significant portion of market price and comprehensive study to find the most efficient solution for transportation problem is urgently required. Although Indonesia is an archipelagic country comprises of thousands of islands, until this present road-based transportation is the predominant mode. Accordingly, to support the economic condition, Indonesia has to take serious attention to keep road condition always in acceptable state.

Road pavement condition consists of functional condition, which is primarily concerned with the ride quality or surface texture of a highway section, and structural condition which measures structural failure of the pavement, the comprehensions analysis and evaluation methods for this condition are surely required.

Pavement conditions can be measured by looking at the severity of functional and structural failures happened. There are two types of pavement failure criteria that commonly used in most cases; 1) limiting the horizontal tension strain at the bottom of bituminous layer which can incur the fatigue cracking, and 2) limiting vertical compression strain at the upper side of subgrade which can incur permanent deformation or rutting. According to those, slippage failure is one of the kinds that can happen at pavement layer. Slippage failure often happens on some location, such as the braking or turning movement at intersection. This failure can be caused by the poor bonding between pavement layers. Some researchers believe that this type of failure results from high horizontal stress and insufficient adhesion between pavement layers (Hachiya and Sato, 1998).

Extensive research has been conducted on the field concerning pavement materials performances. However, only few number researches studied and reported the bonding conditions between pavement layers and their effects to pavement life. Commonly, most of flexible pavement design assumes full bonding between pavement layers. In reality, the bonding conditions are in the range between full adhesion and zero adhesion depends on the property of material and construction quality. The bond between layers is very important to ensure that those layers work together as a composite structure to withstand traffic and environmental (e.g. temperature induced) loadings. To achieve that condition, a thin film of bituminous bond coat (or tack coat) is usually applied at the interfaces. However, full bonding is not always achieved and a number of pavement failures linked to poor bond condition have been reported (Hachiya and Sato, 1997; Raab and Partl, 1999; Hakim, 2002; Sutanto, 2004; Hariyadi, 2007)

Based on the explanations above, road pavement design should be adjusted with the real condition. In this case, design which considers bonding condition between layers should have been applied. Thus, the pavement structure should be modeled with a partial bonding interface. This model will define the real condition and failures that occur to the pavement structure can be detected immediately. Using BISAR software can analyze the partial bonding condition between layers using *Spring Compliance* values.

2. PAVEMENT MODEL

2.1 Pavement Structure Model

Pavement structure model under investigation consist of four layers as shown on Figure 1. The subgrade is assumed to extend to infinity and all pavement layers are assumed to be infinite in the horizontal direction. The pavement is considered as an elastic multilayered system with varying interface condition. In addition, a horizontal loads simulating friction forces combined with a standard dual load is considered. The two critical strains are monitored at bottom of asphalt layer **(ε_h)** and top of subgrade **(ε_v)** which reflect to fatigue cracking and permanent deformation respectively.

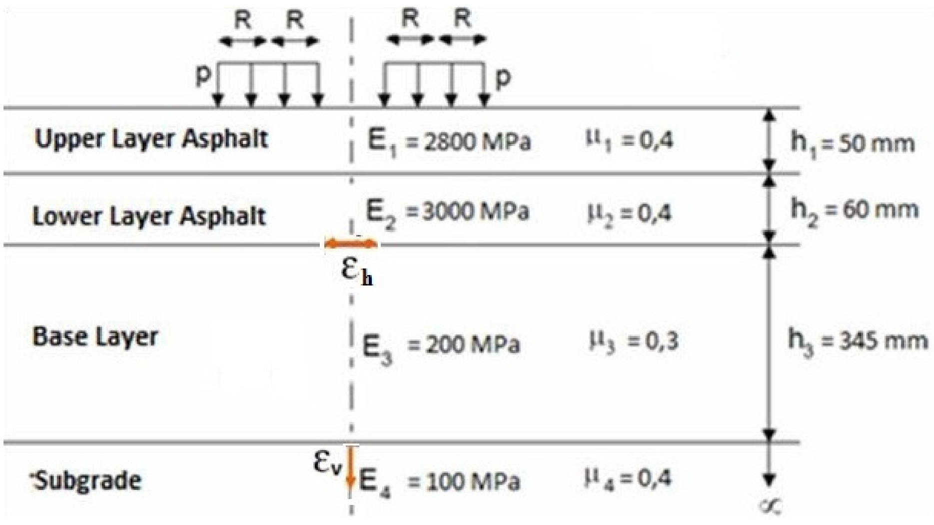

Figure 1. Pavement Structure Configuration

2.2 Load Configuration Model

Standard Dual Wheel configuration loads are used for this study as shown on Figure 2. Coefficients of friction between wheel and pavement surface are assumed in the range between 0.5 – 0.8, horizontal load can be defined by multiply this coefficient with the vertical load value. Horizontal loads are in the range between 10 – 16 kN. The values are produced by following equation :

$$F = f * W \quad (1)$$

where,

F = Horizontal load on contact surface between wheel and pavement surface
f = Coefficient of friction between wheel and pavement surface
W = Vertical load from the wheel

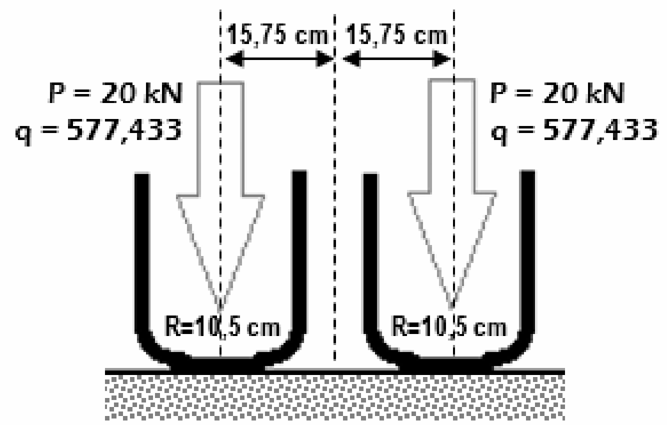

Figure 2. Loads Configuration

2.3 Interface Condition

Two interface conditions have been provided by Burmister (1945) : full friction (i.e. full bond) and frictionless (i.e. full slip), which are only considered two extreme interface conditions and very unlikely because interlayer friction may still exist. Uzan et al. (1978) introduced a method for the solution of elastic layered systems in between those two extreme conditions. They adopted Goodman's constitutive law to explain the interface condition:

$$\tau = Ks\ (\Delta U) \quad (2)$$

where,

τ = shear stress at the interface (in MPa),
ΔU = relative horizontal displacement at the interface (in mm), and
Ks = *Shear Reaction Modulus* of the interface (in MPa/mm).

Using an elastic layered BISAR software which developed by SHELL, it is possible to make a model for the interface with partial condition. The designers of BISAR have developed the

concept of *Shear Spring Compliance* to account for the relative displacements (slip) between pavement layers. The *Shear Spring Compliance* (AK) is the inverse of the shear reaction modulus at the interface between adjacent layers (Ks).
The definition of the *Shear Spring Compliance*, AK, is given by:

$$AK = \frac{relative\ horizontal\ displacement\ between\ layers}{shear\ stress\ acting\ at\ the\ interface}\left[m^3/N\right]$$

(3)

Bonding condition can also be represented by *The Shear Reaction Modulus* (Ks). Hariyadi (2007) classified bonding condition in some ranges of Ks values; partial bonding on the values less than 1,060 MPa/m and full bonding on the values more than 1,060 MPa/m. For the partial condition, there are weak bonding condition on the values less than 405 MPa/m, medium bonding condition on the range between 405 MPa/m and 620 MPa/m, and strong bonding on the range between 620 MPa/m and 1,060 MPa/m. Following Table 1 shows the AK value as the invers of Ks value which are used for this study:

Table 1. Standard Shear Spring Compliance Values

Bonding Parameter	Medium Bonding				Strong Bonding			
Ks (MPa/m)	450	500	550	600	700	750	800	850
AK (m^3/N)	2.22E-09	2.00E-09	1.82E-09	1.67E-09	1.43E-09	1.33E-09	1.25E-09	1.18E-09

3. ANALYSIS OF THE EFFECTS OF BONDING CONDITION

3.1 Influence of Bonding Condition to Critical Strain

Partial bonding condition is applied at the first interface, where located between two asphalt layers. Two Locations are monitores under the wheel and between the wheels. Structural responses with the variation of Ks value can be seen on the Figure 3.

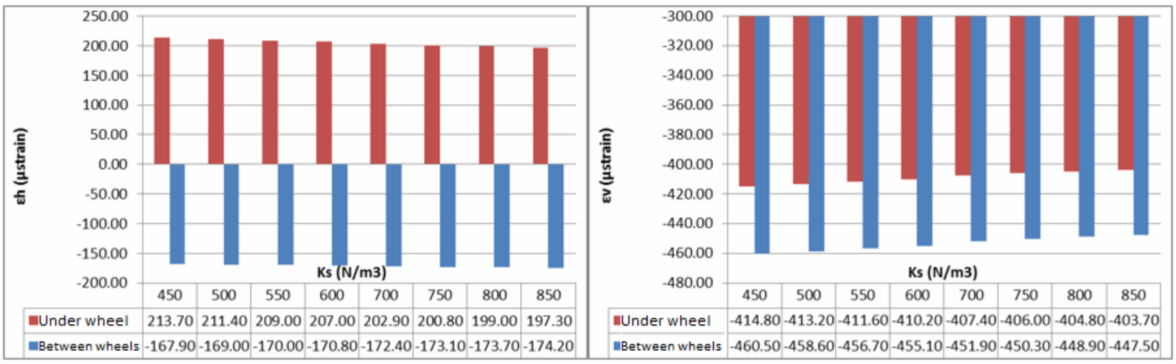

Figure 3. Strains Responses on Partial Bonding Condition between Layers

Based on the Figure 3, strain values are decrease with the increasing of Ks values. The higher strain values (ε_h) occur at the position under the wheel. Meanwhile, the higher strain values (ε_v) occur at the position between the wheels. Positive values are indicating tensile strain, in the other way negative values are indicating compressive strain.

The increasing of Ks values are proportional with the increasing of bonding at the interfaces between layers. In the other hand, strain values are proportional with the decreasing of pavement capacity. In such a way, on partial bonding condition, interfaces with better bonding (represented by higher Ks value) will make higher capacity of pavement structure and lengthen pavement life.

3.2 The influence of Horizontal Forces to Critical Strain

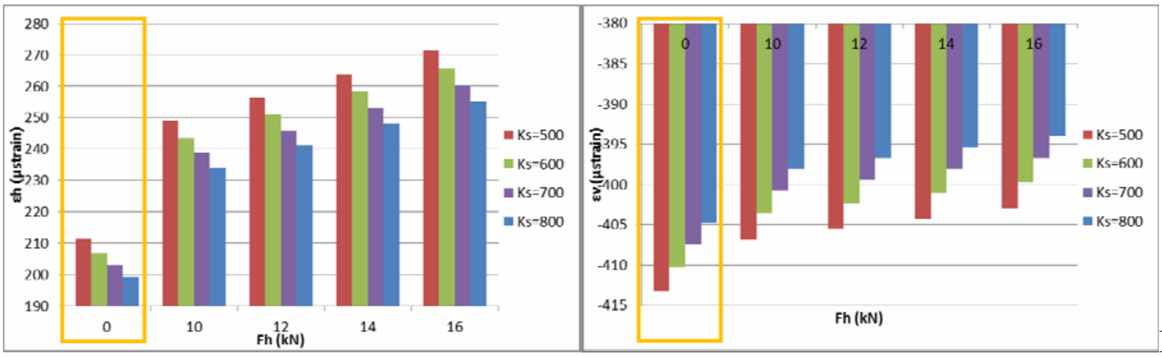

Figure 4. Strain Responses on Variations of Horizontal Force

This study also analyzed the effects of horizontal force to critical strain as pavement structural responses with partial bonding condition applied at the interface between asphalt layers. Figure 4 shown the decreasing of horizontal strain on the bottom of asphalt layer (ε_h) are proportional with the increasing of horizontal force. The opposite results for vertical strain on the top of subgrade (ε_v), which are decreasing proportionally. It is important to know if vertical and horizontal forces are applied, this will effect to horizontal stress which are dissipated quickly in the approximately 100 mm depht (Horak, E. et al, 2009). On the other hand, the critical strain at the top of subgrade is decreased cause of this condition. This reflect to the fatigue failure criteria is dominant in applying horizontal force to pavement structure.

3.3 Influence of Bonding Condition to Critical Strain Location

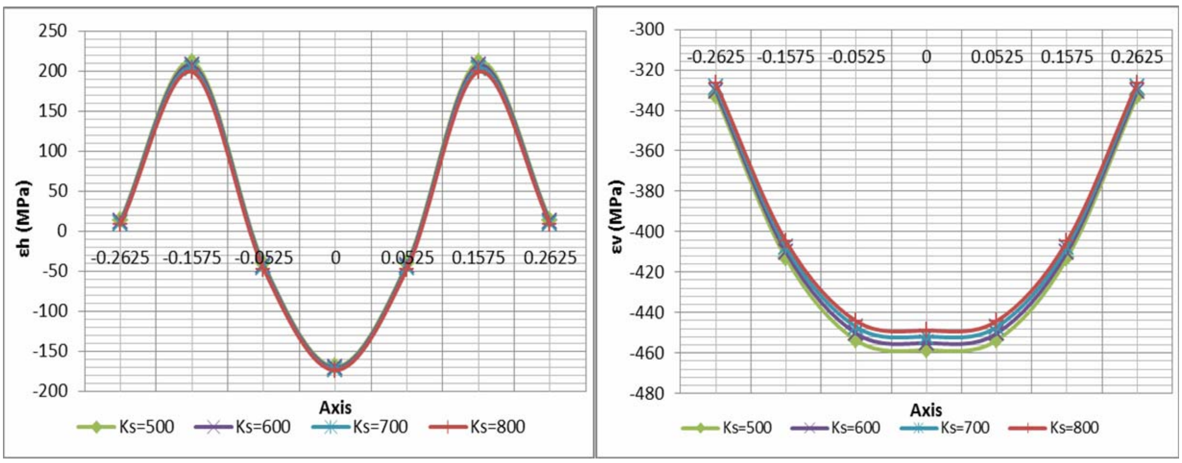

Figure 5. Strain Responses at Critical Locations

Figure 5 shown critical horizontal tensile strain on the bottom of asphalt layer were occurred under the wheel (0.1575 from axis). Whereas critical vertical compressive strain on the top of subgrade were occurred between the wheels (at axis). The same trends happened for every variations applied on this study. Critical responses can move from under the wheel to between the wheels due to the influence of contiguous load from each wheel.
As shown on Figure 5, all of the curves which show the different bonding condition are concide. This conlude that bonding condition is not influence to critical strain location in flexible pavement structure.

3.4 Influence of Upper Asphalt Layer Thickness to Critical Strain

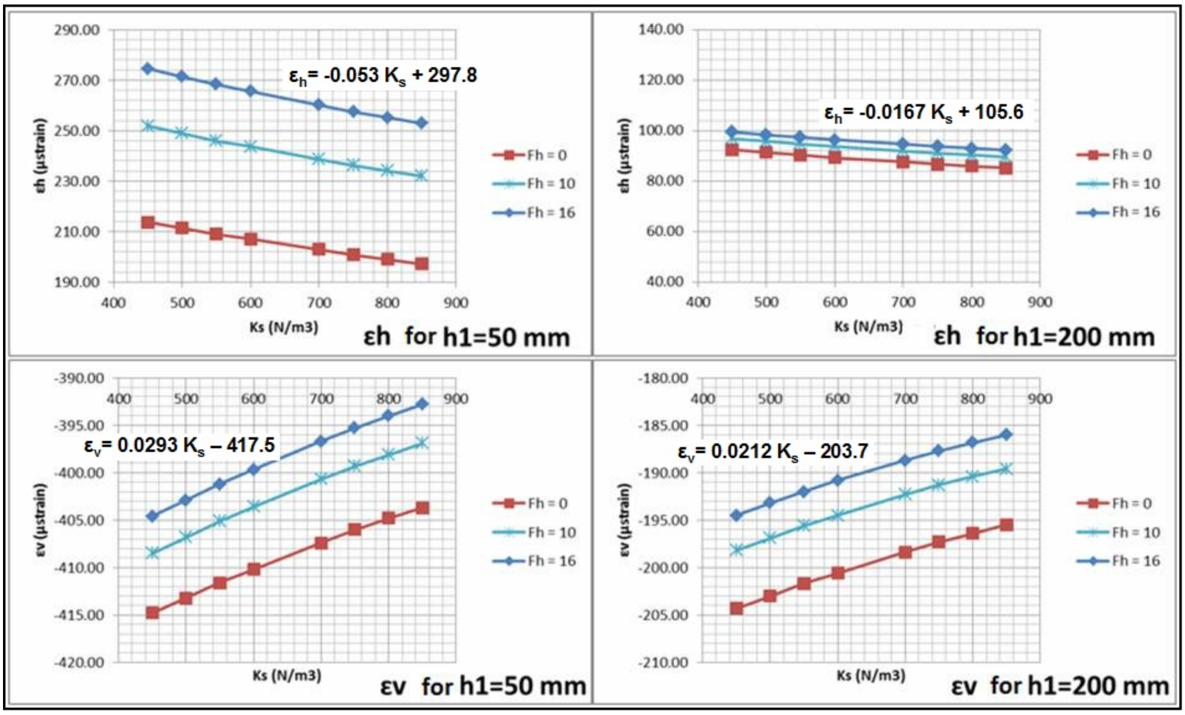

Figure 6. Comparison of Strain Responses on the Variations of Upper Layer Asphalt Thickness

In order to analyze the influence of Upper layer Asphalt thickness, the BISAR calculation are carry out to 50 mm and 200 mm layer thickness. In addition, horizontal force is also applied to see the effect to pavement responses. As shown on Figure 6, for the thick layer (200 mm) all the curves are coincide. This reflect to the horizontal forces are not sensitive to changing of horizontal strain on thick asphalt layer. However, different condition were occurred for vertical strain on the top of subgrade, where the curves are not coincide.
The gradient of the curve indicate the influence of bonding condition to the thickness of upper layer asphalt. As shown on Figure 6, the curve gradient for thin asphalt layer (50 mm) are higher than thick asphalt layer (200 mm). This show that poor bonding will take more influence on thin asphalt layer than thick asphalt layer as well.

4. CONCLUSIONS

Following conclusions could be drawn from this study:

1. Better bonding condition at the interface between layers will cause the decreasing of critical strain. As the results, the better structural capacity can be achieved with better bonding between layers.
2. In applying horizontal force in pavement structure, the horizontal stress will dissipate quickly the structural respons in the approximately 100 mm depht. On the other hand, the critical strain at the top of subgrade is decreased cause of this condition. This reflect that the fatigue failure criteria is dominant in applying horizontal force to pavement structure.
3. Bonding condition and horizontal load were give more significant influence to the structural responses under the wheel, relative to their influence to the responses between the wheels. The bonding condition is not influence to critical strain location in flexible pavement structure
4. The horizontal forces are not sensitive to changing of horizontal strain on thick asphalt layer. The poor bonding will take more influence on thin asphalt layer than thick asphalt layer.
5. The assumption of full bonding interface and no horizontal force applied in flexible pavement structure which are used in pavement design method may not appropriate and this may cause the pavement failure which are not early anticipated.

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