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Evaluation of flexural fatigue behavior of two layered asphalt beams with geosynthetic interlayers using Digital image correlation

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ABSTRACT

In the current study, the flexural fatigue performance of two layered asphalt beams with and without geosynthetic interlayers has been evaluated using digital image correlation (DIC) technique. The two layered asphalt specimen consists of an old deteriorated pavement slab as the bottom layer, a conventional tack coat along with geosynthetic interlayers and a bituminous concrete (BC) mix compacted as an overlay.

The digital images are recorded at a specific interval of load cycles during flexural fatigue testing (four point bending) using a high definition digital camera. The displacement fields obtained from the digital images are analyzed to provide an information on the crack width, crack height and the tensile strains to study the crack initiation and crack propagation stages of beam specimens. The data obtained from the DIC analysis is validated with the vertical deformations measured during the fatigue testing. The results correlate well with an acceptable level of accuracy. The DIC data depicted that the tensile strains are as high as 4.75% at the crack tip in the control specimens at 335 load cycles against 1.42% in a polyester grid interlayer at 13116 cycles.

Keywords: *Digital image correlation, geosynthetic interlayers, HMA overlays, flexural fatigue testing.*

1 INTRODUCTION

2 An efficient pavement system is essential for the socio-economic growth of any nation as the
3 roadways are one of the major modes of transportation. A pavement system is said to be effective
4 when it provides a smooth and safe ride quality to the road users. Also, it should be capable of
5 withstanding the heavy traffic loads and transferring the stresses carefully to the layers below,
6 which depends on the quality of materials and construction. If not, the pavements are observed to
7 develop various defects and needs to be rehabilitated. The traditional rehabilitation technique of
8 placing hot mix asphalt (HMA) overlays are found to be a temporary solution, as the existing
9 cracks are observed to propagate through the new HMA overlays, popularly known as reflection
10 cracking (1). The reflection cracking process consists of two stages namely: the crack initiation
11 and the crack propagation stages (2). The crack initiation takes place at the bottom of the existing
12 asphalt layer where the tensile strains are high and eventually the crack propagates to the surface
13 of the overlay causing a bottom-up fatigue cracking (3, 4). To avoid or to resist these effects, a
14 stress absorbing membrane interlayer (SAMI) or a geosynthetic interlayer is placed between the
15 old and new pavement layers to help absorb the tensile stresses and to control the crack propagation
16 by providing stress relief from underneath (5, 6). However, there is a significant complexity in the
17 analysis of crack propagation of HMA mixtures, as they are heterogeneous in nature and the same
18 has been an obstacle to incorporate fracture mechanics based models in asphalt concrete mixes (7).
19 The most common method employed to predict the crack initiation and propagation in the asphalt
20 mixtures are by placing sensors like strain gauges and linear variable differential transformers
21 (LVDT). Although these techniques are easy to install, they do not provide the accurate strain
22 values, as the measurement location has to be fixed prior to the test (8). To overcome this problem
23 and to improve the crack identification procedure in the asphalt mixtures, a high resolution full-
24 field measurement technique is required (9).

25

26 BACKGROUND

27 Since past two decades, there has been an extensive development in the non-contact, full-field
28 optical measurement techniques to determine and analyze the heterogeneities in the composite
29 material (10). The various non-contact optical techniques include interferometric techniques like
30 holographic interferometry and speckle interferometry. Also includes non-interferometric
31 techniques like grid method and digital image correlation (DIC) (8, 11 & 12). The non-
32 interferometric techniques are found to be advantageous over the interferometric techniques due
33 to their ease in testing and providing the displacement and strain contours in the specimen
34 accurately. DIC is one such non- interferometric optical technique first proposed in the 1980s and
35 later improvised to study the 2-dimensional strains and displacements in various types of materials
36 including composites, concrete and asphalt mixtures (8). Choi and Shah (13) are the first to employ
37 the DIC technique to study the deformation of concrete under compression successfully. Further,
38 Kim and Wen (14) employed the DIC technique to measure the displacement and/or strains in
39 asphalt mixtures. Later, number of researchers (7, 9 & 15) has made use of DIC technique to study
40 the cracking behavior of asphalt mixtures using various testing programs like indirect tensile
41 strength test and semi-circular bending tests. The results have revealed that the cracking in asphalt
42 mixtures takes places around the coarse aggregates. It is also observed using image analysis that
43 the fracture mechanics based models can be used to evaluate the performance of asphalt mixtures
44 (16).

45 Hamrat et al. (17) studied the flexural cracking behavior of normal and high strength fiber
46 concrete beams under static loading using DIC and found that the DIC technique was effective in

1 measuring the strain fields completely till failure. Similarly, the flexural cracking behavior of
 2 reinforced concrete beams under static and repeated loading conditions were evaluated by Mahal
 3 et al. (18) using DIC technique. They found that the DIC technique was effective both under static
 4 and repeated loading conditions, in detecting the crack initiation, crack patterns and the
 5 corresponding displacement and strain fields effectively. The DIC results were also observed to
 6 correlate well with the results obtained from the conventional instrumentation showing a better
 7 accuracy than the latter.

8 With this background, it can be summarized that the DIC technique is effective in providing
 9 the complete details of displacement and strains in the specimens accurately. In the current study,
 10 an attempt has been made to understand the flexural fatigue behavior as well as the cracking
 11 mechanism associated with the two layered asphalt beam specimens with and without geosynthetic
 12 interlayers. The asphalt specimens were evaluated under four point repeated load bending test
 13 using DIC technique. In this study, emphasis was given to the field scenario, in which, the HMA
 14 overlay was placed on an old pavement layer extruded from a distressed pavement section.

15 MATERIALS AND SAMPLE PREPARATION

16 Geosynthetic Interlayer

17 There are various types of geosynthetic interlayers currently available for a designer to choose
 18 from to improve the performance of an HMA overlay. In the current study, three types of
 19 geosynthetic interlayers were employed to understand the effectiveness of interlayers in improving
 20 the flexural fatigue performance of the HMA overlays and they are:

21 Biaxial polyester grid (I_1) manufactured with a high tenacity and molecular weight polyester yarns,
 22 which are knitted together to form a grid structure with a mesh opening of 18 mm as shown in
 23 Figure 1a. The biaxial polyester grids are completely coated with polymeric modified bitumen to
 24 improve their adhesive properties when placed between the old and new pavement layers.
 25

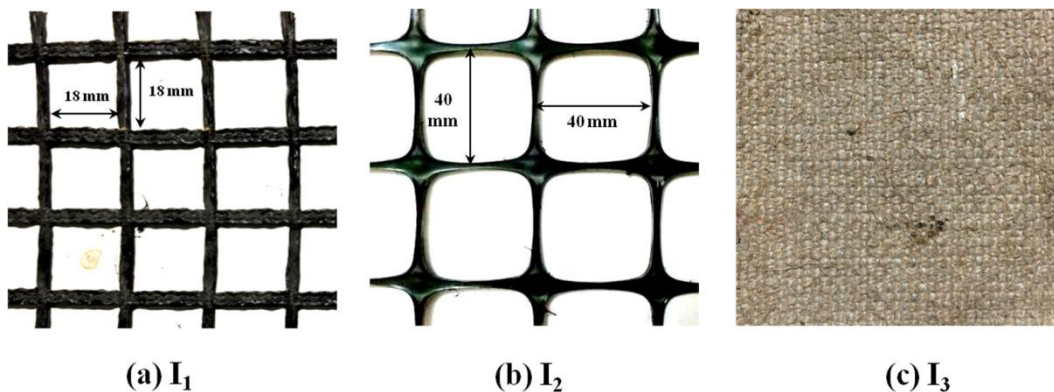


FIGURE 1 Geosynthetic interlayers.

Biaxial polypropylene grid (I_2) manufactured from a 4 mm thick polypropylene sheet and has a
 square aperture of 40 mm as shown in Figure 1b. Geo-jute mat (I_3) manufactured from the natural
 geo-jute materials like fibers and/or threads by either machine weaving or manual weaving to form
 about 1 mm thick mat structure without any apertures as shown in Figure 1c. Table 1 reports the
 specifications of the geosynthetic interlayers in order to compare the mechanical properties of each
 interlayer type.

TABLE 1 Physical properties of geosynthetic interlayers

Specifications	Polyester grid (I ₁)	Polypropylene grid (I ₂)	Geo-jute mat (I ₃)
Tensile strength at 2% strain (20)	6.05 (MD) 6.57 (CMD)	9.02 (MD) 12.22 (CMD)	2.71 (MD) 3.74 (CMD)
Tensile strength at 5% strain (20)	9.20 (MD) 10.07 (CMD)	22.52 (MD) 24.58 (CMD)	24.38 (MD) 6.34 (CMD)
Ultimate tensile strength (kN/m) (20)	48.20 (MD) 50.87 (CMD)	34.95 (MD) 42.00 (CMD)	25.24 (MD) 20.62 (CMD)
Strain at ultimate tensile strength (%) (20)	18.8 (MD) 21.33 (CMD)	10.82 (MD) 12.71 (CMD)	5.07 (MD) 13.34 (CMD)
Thickness (mm)	2	4	1
Aperture size (mm×mm)	18 × 18	40 × 40	-

*MD-Machine direction, *CMD-Cross-machine direction, na

Binder Tack Coat and Asphalt Concrete

The asphalt binder material used in the current study has a penetration value of 66 as determined by bitumen penetration test and can be classified as penetration grade (PG) 60-70 bitumen. The binder has a specific gravity of 1.01 and a viscosity of 460 centipoise at 60 °C as determined from Brookfield viscometer. The softening point of the binder is 52 °C, while the flash point and fire points are 340 °C and 360 °C respectively.

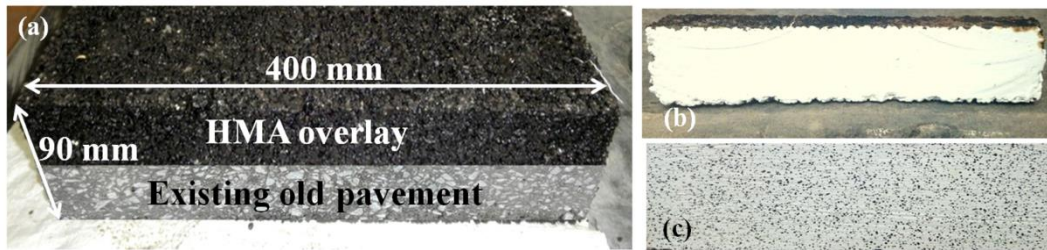
The bituminous concrete (BC) mix having a nominal aggregate size of 13 mm is used as a overlay in the current study. The hot mix was prepared in the mix plant and transported to the laboratory. The mix has a PG-60/70 binder with an optimum bitumen content of 5.5 %. The strength and flow value was found to be 14.25 kN and 2.5 mm respectively from Marshall stability test performed as per ASTM D6927 (19).

Specimen Preparation

The two layered asphalt beam specimens with and without geosynthetic interlayers for flexural fatigue testing and corresponding DIC analysis were prepared in different stages. During the first stage, an old deteriorated pavement layer extruded from an existing highway is carefully cut into a dimension of 400 mm length, 300 mm width and 45 mm thickness. The next stage consists of preparing a two layered asphalt slab of 400 mm length, 300 mm width and 90 mm thickness. The two layered asphalt slab consists of an old pavement block placed as a bottom layer, above which the binder tack coat is applied at the rate of 0.25 kg/sq.m (21). The geosynthetic interlayers are placed at the interface as per experimental program before compacting a 45 mm thick BC mix as a HMA overlay as shown in Figure 2a. The overlay is compacted using a 5 kg static weight compactor with a 50 cm height of fall. During the next stage, the two layered asphalt slabs prepared were cut into beams of 400 mm length, 50 mm width and 90 mm depth. The beam specimens were further prepared for the digital image analysis by uniformly applying white paint on one of the sides of the specimen as shown in Figure 2b. A black paint under controlled pressure was sprayed carefully on the painted side of the specimen to obtain a uniform random speckle pattern throughout the specimen as shown in Figure 2c. The specimen is monitored carefully to record the minute changes in the speckle pattern of deformed and undeformed images. The changes in the

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1 speckle pattern of deformed images are further analyzed to calculate the full-field displacements
 2 and strain accurately using DIC technique.
 3



4
 5 **FIGURE 2 Two layered asphalt beam specimen preparation.**

6 **EXPERIMENTAL PROGRAM**

8 **Repeated Load Four-Point Bending Test**

9 The flexural fatigue performance of the two layered asphalt beam specimens with and without
 10 interlayers is studied with the help of a repeated load test under four-point bending configuration
 11 performed as per ASTM D7460 (22). Figure 3 shows a schematic of typical four-point bending
 12 test setup used in the current study which consists of a loading actuator, four point roller support
 13 and clamps to hold the specimen in position. The test is performed under a stress controlled mode
 14 and the load is applied with the help of a computer controlled servo hydraulic actuator system. A
 15 continuous haversine type loading pattern was applied repeatedly at a frequency of 1 Hz to
 16 replicate the live traffic condition (equivalent to a single axle load contact pressure of 550 kPa).
 17 The maximum load to be applied corresponding to a contact pressure of 550 kPa was calculated
 18 using Equation 1 (22).
 19

$$20 \quad \sigma_f = \frac{Pl}{bh^2} \quad (1)$$

21
 22 Where, σ_f is the maximum flexural stress in MPa, P is the maximum load applied in kN, l
 23 is the length of the beam in m, b is the width of the beam in m and h is the thickness of the beam
 24 in m.

25 To understand the crack initiation and crack propagation stages during the flexural fatigue
 26 test, a full-field continuous crack and/or strain monitoring technique is most essential. In the
 27 current study, the crack information of two layered asphalt specimens viz. the crack evolution,
 28 crack patterns, crack width, crack height, maximum tensile strains and their location is determined
 29 accurately with the help of DIC technique.

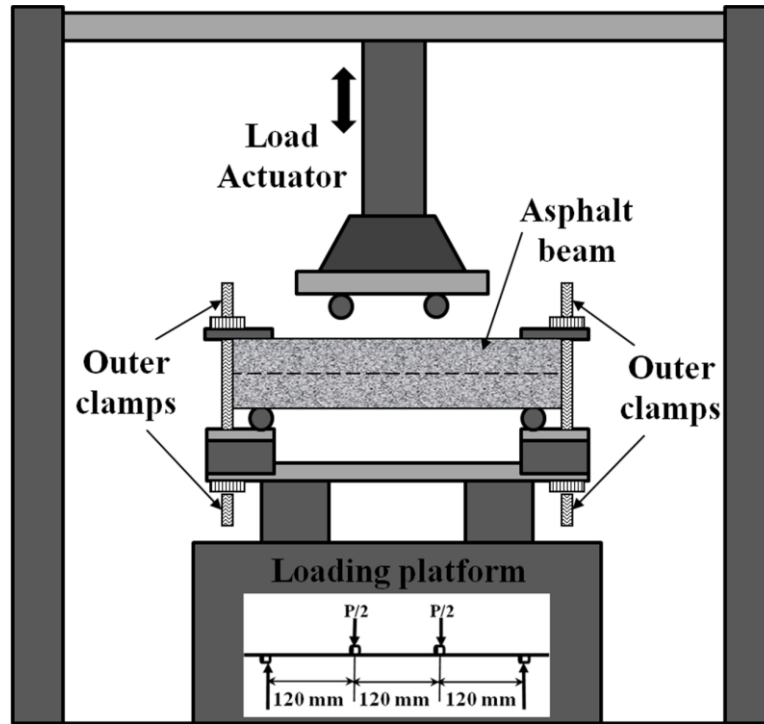


FIGURE 3 Schematic of four point bending (flexural fatigue) test setup.

Digital Image Correlation Technique

The DIC is an optical and non-contact metrology based on the digital image processing technique. DIC technique is effectively employed to measure the full-field displacements and calculate the strains from the deformed images of the specimen. The fundamental principle of DIC technique is that the pixel location (gray level) of the deformed image is compared with the pixel location (gray level) of the undeformed image for any changes. The changes in gray levels or pixel locations are further analyzed to calculate the full-field displacements using the following concept. The distribution of gray levels for any pixel area in the undeformed image is represented by a function $f(x, y)$ and the same function in a deformed image is represented as $f(x_t, y_t)$. The relationship between the distribution of gray scale levels in deformed and undeformed image for a pixel area is given by following equations (23):

$$f(x, y) = f(x_t, y_t) \quad (2)$$

The transformation of pixels in undeformed image to deformed image takes place as follows:

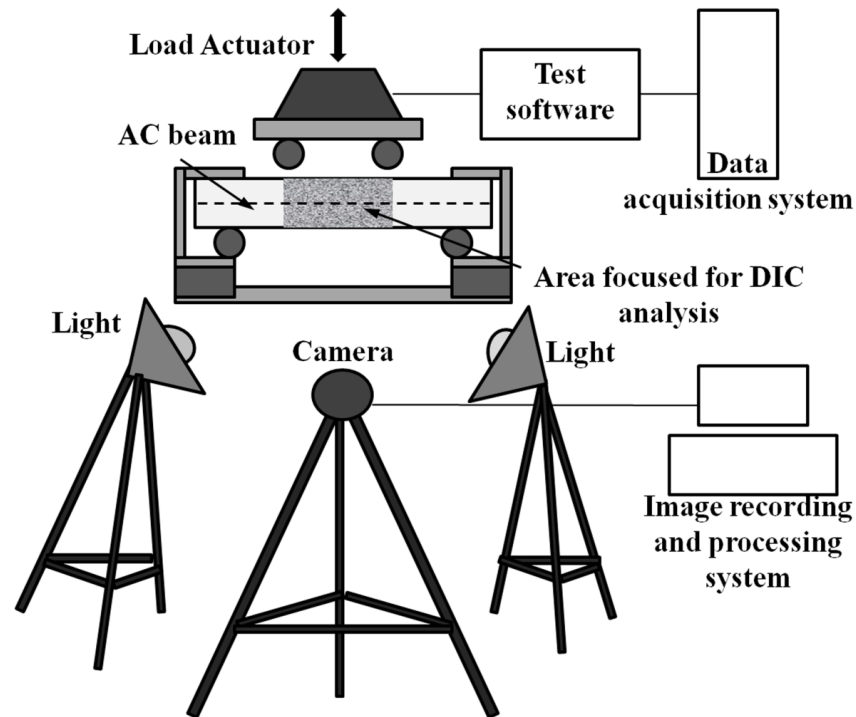
$$x_t = a_1 + a_2x + a_3y + a_4xy \quad (3)$$

$$y_t = b_1 + b_2x + b_3y + b_4xy \quad (4)$$

Where, the values a_1 and b_1 describes the pixel translation at the center and the other values describe its deformation and rotation (18).

Figure 4 shows the schematic of DIC test setup, which consists of a digital camera with a constant power supply, appropriate lighting arrangement, a laptop or a computer connected to the

1 digital camera to record the images continuously at a specified frequency through a commercial
 2 software. The typical DIC test process consists of recording an image showing the actual
 3 dimension of specimen in millimeters, which is used to convert the gray scale image from digital
 4 units (pixels) to physical units (millimeters). The image recorded is known as calibration image as
 5 it is used to calibrate the scale to millimeters. After recording the calibration image, an undeformed
 6 image of the specimen is recorded before applying the load, which is known as a reference image.
 7 Further, continuous images are recorded at a specified interval of time during the testing program
 8 until failure, i.e. complete fracture of the specimen in this case. The recorded images are further
 9 processed using a commercial software VIC-2D, which observes and records the change in gray
 10 level of deformed images w.r.t the reference image carefully. The deformed images are correlated
 11 by dividing the area of interest (as shown in Figure 4) into a number of small areas known as
 12 subsets and any further change in the gray levels of each subset is noted. The change in gray levels
 13 of deformed images w.r.t the reference image is used to calculate the full field displacement and
 14 strains using an iterative technique. Using this technique, an increase in the crack width and height
 15 can also be calculated with the help of inbuilt tools like measurement of crack opening
 16 displacement (COD) in the software.
 17



18
 19
 20
 21 **FIGURE 4 Schematic of DIC test setup**

22 **RESULTS AND DISCUSSIONS**

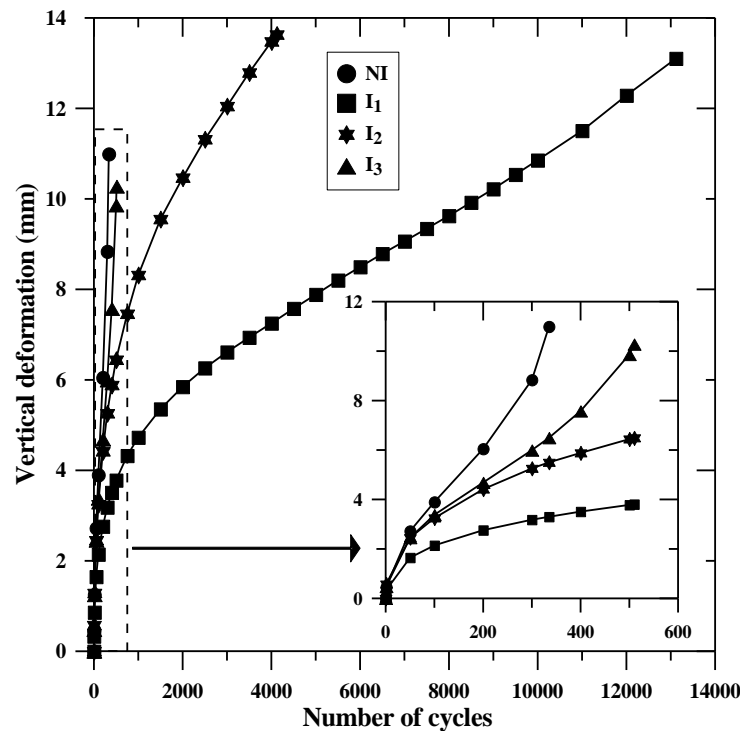
23 **Repeated Load Test Results**

24 The repeated load test performed in a stress controlled mode under a four point load configuration
 25 helps to understand the flexural fatigue behavior of the two layered asphalt beam specimens with
 26 and without interlayers. The repeated load was applied continuously on the specimen and an
 27 increase in the vertical deformation of the specimen was witnessed with an increase in the number
 28 of load repetitions. The increase in vertical deformation causes the dissipation of energy from the

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1 specimen and reduces the stiffness, which further causes the complete fracture (failure) of the
2 specimen.

3 Figure 5 presents the fatigue test results for the two layered asphalt beam specimens with
4 and without interlayers in the form of variation of vertical deformation with a number of load
5 cycles (N). The vertical deformation-load cycle curve for NI and I₃ specimens are not clearly
6 visible as they could not resist a large number of load cycles before failure. The inner plot in Figure
7 5 is provided to give a clear idea about the failure of NI and I₃ specimens and also to distinguish
8 between the performances of different specimens tested. It can be observed that the vertical
9 deformations of NI, I₁, I₂ and I₃ specimens after 100 load cycles are 4 mm, 2 mm, 3 mm and 3.5
10 mm respectively. Similarly, after 300 load cycles, the vertical deformation values were observed
11 to be 9 mm, 3 mm, 5 mm and 6 mm respectively for NI, I₁, I₂ and I₃ specimens. This proves the
12 fact that the presence of interlayer at interface zone reduces the vertical deformation by restricting
13 the crack propagation. Whereas, the NI specimen has no interlayer and the crack propagates
14 through the interface zone into the overlay easily without any obstruction and fractures the
15 specimen completely. However, among the specimens with interlayers, I₁ showed a greater
16 resistance to crack propagation followed by I₂ and I₃, but the cracks were observed to propagate in
17 the horizontal direction at the interface zone reducing the interface bond strength of interlayers.
18



19
20 **FIGURE 5 Variation of vertical deformation with number of cycles**
21

22 To evaluate the performance of two layered asphalt specimens with interlayers, a non-
23 dimensional performance factor known as improvement ratio (I_R) is introduced. The improvement
24 ratio can be defined as the ratio of fatigue life of asphalt specimen with and without interlayer and
25 is mathematically expressed as:
26

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$$I_R = \frac{N_I - N_{NI}}{N_{NI}} \quad (5)$$

Where, N_I is the fatigue life of specimens with interlayers and N_{NI} is the fatigue life of specimens without interlayers.

Figure 6 shows the improvement ratio for specimens with interlayers at different vertical deformation values. It can be observed that the improvement ratio has increased with the increase in vertical deformation values. The I_R values are observed to be almost similar for all the specimens with interlayers at low vertical deformation values, but after a vertical deformation of 4mm, the I_R of I_1 specimen increases from 3 to 9 at 6 mm vertical deformation. Similarly, an improvement of 1.5 at 6 mm vertical deformation is observed in the I_2 specimen. The presence of interlayers has shown a great improvement in the fatigue life of two layered asphalt specimens as they absorb the high tensile stress responsible for the crack propagation.

However, a detailed information about the flexural fatigue performance as well as the cracking mechanism of two layered asphalt beam specimens with and without geosynthetic interlayers can be obtained using DIC technique as explained in the following sections.

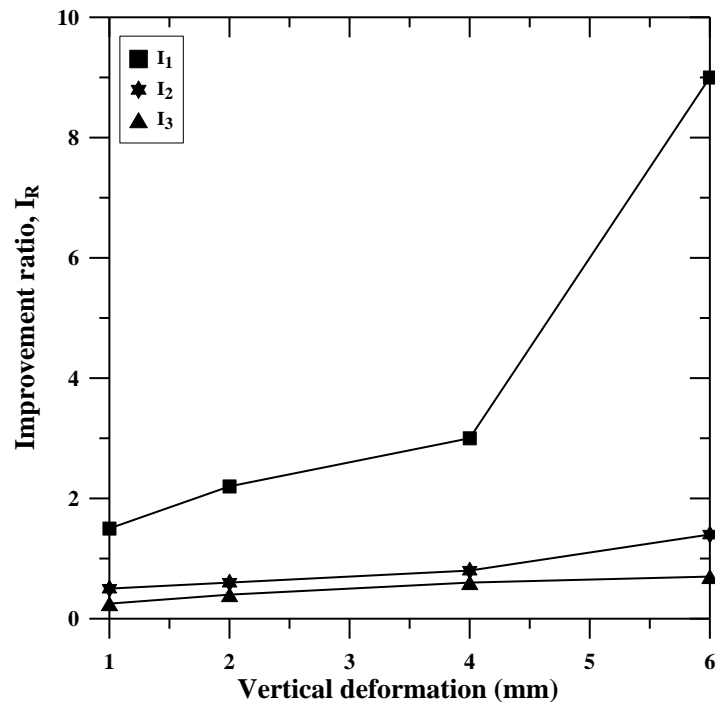


FIGURE 6 Improvement ratio for different interlayers

DIC Analysis

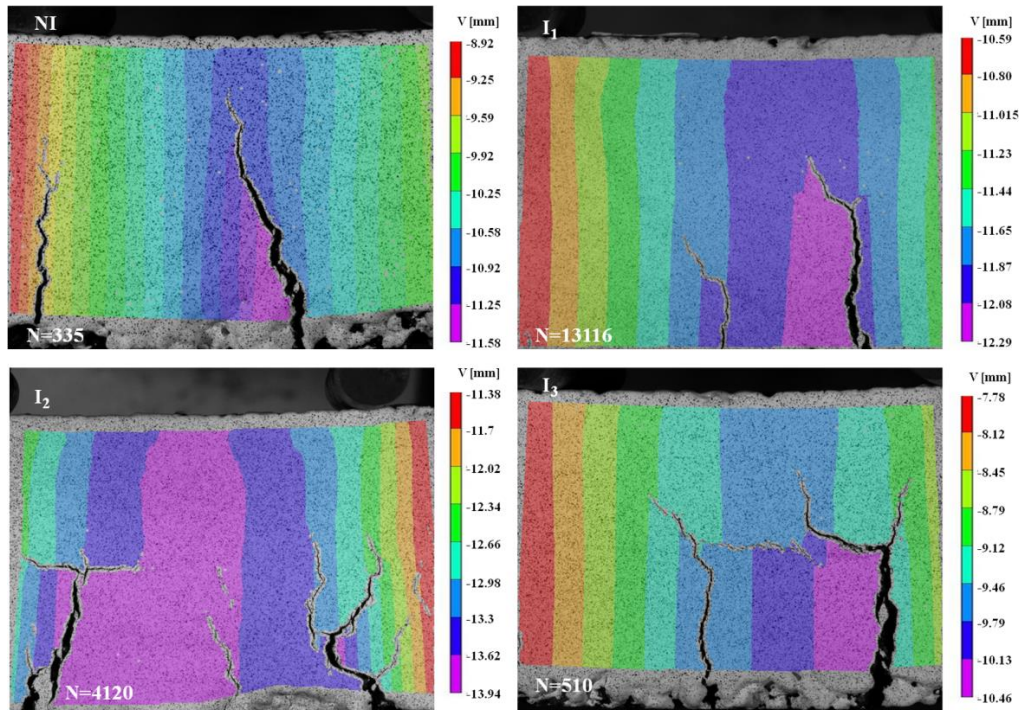
This section describes the application of DIC technique to study the flexural fatigue performance and the cracking mechanism of two layered asphalt beam specimens with and without geosynthetic interlayers.

Deflection

The deflection of the beam is its vertical deformation at the mid-span length. The vertical deformation at any point on the specimen surface can be determined from the displacement fields

1 obtained at different load cycles during the flexural fatigue test. The displacement fields are
 2 obtained in the form of vertical deformation bands as shown in Figure 7. It is to be noted that in
 3 each color band, the vertical deformations are uniform and the downward deformation is
 4 considered as negative in the analysis. The vertical deformation values obtained from the DIC at
 5 the mid-span of the specimen are plotted against the mid-span vertical deformation values obtained
 6 from the actuator displacement sensors for all the test specimens as shown in Figure 8, as a function
 7 of number of load cycles. It can be observed that the values obtained from DIC and actuator
 8 displacement sensors are similar and there is no significant variation in the values. These results
 9 indicate that the DIC technique employed in the current study is suitable to understand and evaluate
 10 the flexural fatigue behavior of two layered asphalt specimens with and without interlayers under
 11 repetitive loading conditions. From Figure 8, it can also be observed that the specimen without
 12 interlayer (NI) could resist only a 335 load cycles, whereas the specimens with interlayers
 13 performed considerably well in improving the fatigue life of overlays at the same vertical
 14 deformation value.

15



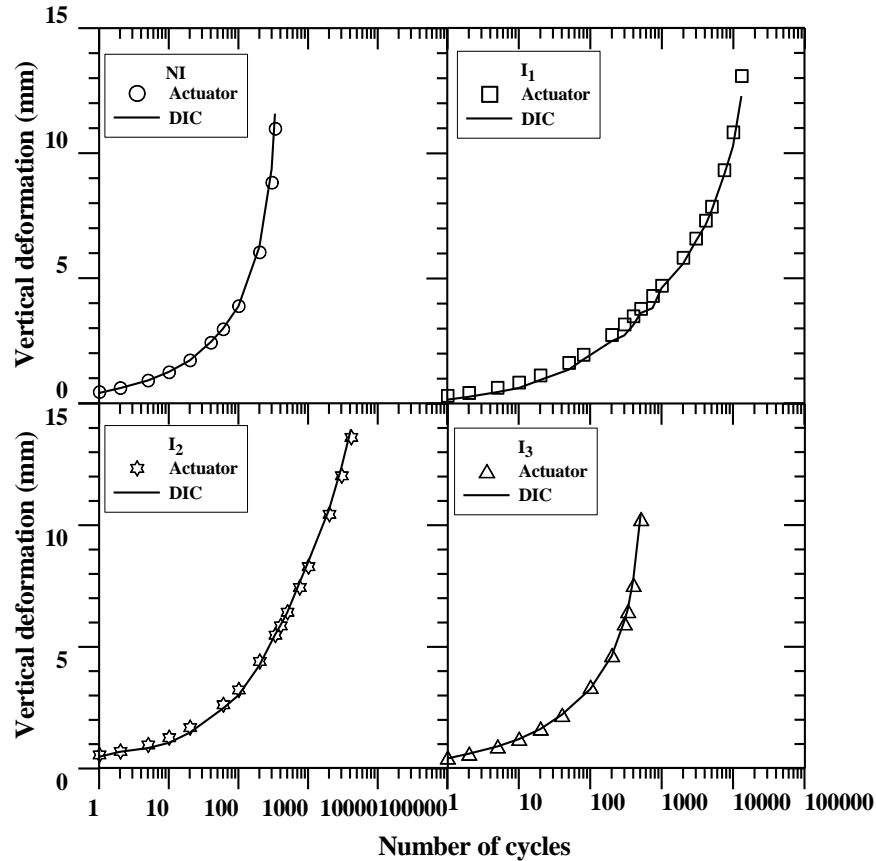
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FIGURE 7 Variation of vertical deformation bands for asphalt beams at failure - DIC analysis

18

19



1
2 **FIGURE 8 Comparison of vertical deformation values obtained from actuator and DIC.**

3
4 *Crack evolution and patterns*

5 The variation of tensile strain with number of load cycles was analyzed to understand the crack
6 evolution and their patterns in the various specimens tested in the current study. Figures 9 (a, b, c
7 and d) shows the tensile strain contours for specimens at crack initiation and failure stage as
8 obtained from DIC analysis. It can be observed clearly that the crack is initiated after 20, 80, 60
9 and 40 load cycles in NI, I₁, I₂ and I₃ specimens, respectively and the corresponding vertical
10 deformations at crack initiation were found to be 1.73 mm, 1.97 mm, 2.63 mm and 2.23 mm
11 respectively. From the above discussion, it can be understood that the crack initiation of two
12 layered asphalt specimens took place within a vertical deformation value ranging from 1.5 mm to
13 3 mm. This information is crucial in the real field scenario, where the crack initiation point plays
14 a major role in selecting the grade of bitumen concrete.

15 From Figure 9a, it can be visualized that after the crack initiation at 20 load cycles, the
16 specimen failed completely at 335 load cycles. The crack is observed to be propagating through
17 the interface zone and reaching the overlay within a lesser load cycles (335) after the crack
18 initiation. However, in the case of specimens with interlayers, it is observed that the crack
19 propagation process is comparatively slow after crack initiation. The I₁ specimen (Figure 9b)
20 resisted the crack propagation effectively till 13116 load cycles before reaching failure, although
21 the cracks were initiated after 80 load repetitions. It was observed that the cracks propagated till
22 the interface zone with the increase in load repetitions and the interlayer placed at the interface
23 zone resisted the further propagation of the crack by absorbing the high tensile stress and the cracks
24 were observed to be redirected in the horizontal direction. Similar observations were made in other

1 specimens with interlayers (I_2 and I_3). However, in the I_3 specimen (Figure 9d), the cracks were
2 observed to spread very quickly in the horizontal direction, as the interlayer does not have any
3 apertures to encourage the through hole bonding between the old and new pavement layers.
4 Although the I_2 specimen (Figure 9c) has an interlayer with a maximum aperture size, the
5 performance life was observed to be less than the I_1 specimen. The reason would be that the I_2
6 interlayer has a smooth surface on both sides with a thickness of about 4 mm, while the I_1 specimen
7 is only 2 mm thick and also has a polymer modified bitumen coating to enhance the interface bond
8 strength of the interlayer. This fact proves that the improvement in fatigue performance depends
9 on the material composition of the interlayer, the thickness of interlayer and the bonding ability of
10 interlayer with the adjacent layers.

11

12 *Crack width and crack height*

13 The crack widths can be estimated by measuring the longitudinal displacements at the bottom-
14 most region of the specimen face by creating a section at that location (18). The crack widths can
15 also be measured by using crack opening displacement (COD) tool available in the software
16 package. In the current study, the COD tool was employed to estimate the crack width effectively
17 in the beam specimens. A small rectangular section is created in the bottom region of specimen
18 face and the longitudinal component within the rectangular section was carefully examined for any
19 sudden jumps and the magnitude of the jump provides an accurate estimate of the crack width. The
20 variation of mean crack width with number of load cycles is plotted as shown in Figure 10b. It is
21 observed that there is an increase in the mean crack width with an increase in the number of load
22 cycles. It can also be visualized that the crack width for NI specimen is 0.74 mm at failure (335
23 cycles), while the specimens with interlayers are observed to have a lesser crack width at failure
24 with I_1 having a least crack width of 0.47 mm at 13116 cycles. Similarly, I_2 and I_3 specimens
25 showed a crack width of 0.56 mm and 0.57 mm at 4120 and 510 cycles respectively. This reduction
26 in crack width shows that the presence of interlayers restrict the crack opening by absorbing the
27 high tensile stress responsible for crack propagation. However, as expected the I_1 specimen has a
28 lesser crack width than other specimens due to the high tensile strength of the interlayer and strain
29 relieving effect provided by the interlayer.

30 The crack height was estimated based on the color bands obtained post processing of DIC
31 images. The vertical component at the crack tip and at the bottom of crack was measured using
32 point tool and the difference between the vertical component at the crack tip and at the crack
33 bottom gives the corresponding crack height. The crack height for all the specimens at different
34 load cycles was determined and the variation of maximum crack height with the number of load
35 cycles is plotted as shown in Figure 10a. It can be observed that the presence of interlayers have
36 restricted the crack height (crack propagation in the vertical direction) until the interlayer was
37 effective. The shallowest cracks of 54.35 mm were observed in the case of I_1 specimen even after
38 resisting 13116 load cycles, whereas, the deepest cracks of 70.89 mm were observed in NI
39 specimen at a lesser load repetitions (335 cycles). However, the I_2 and I_3 specimens were observed
40 with a crack depth (height) of 56.2 mm and 66.5 mm respectively at failure.

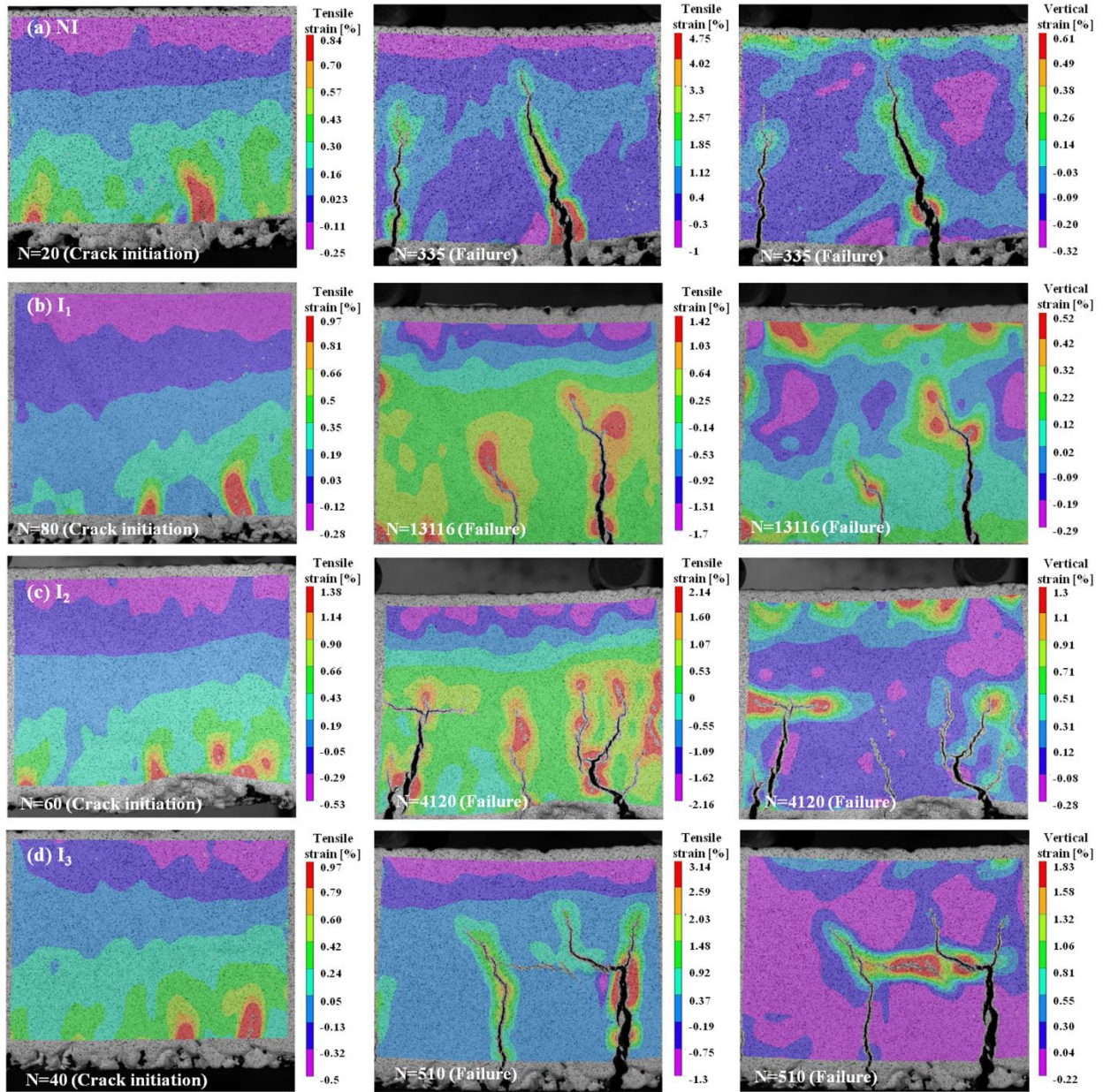
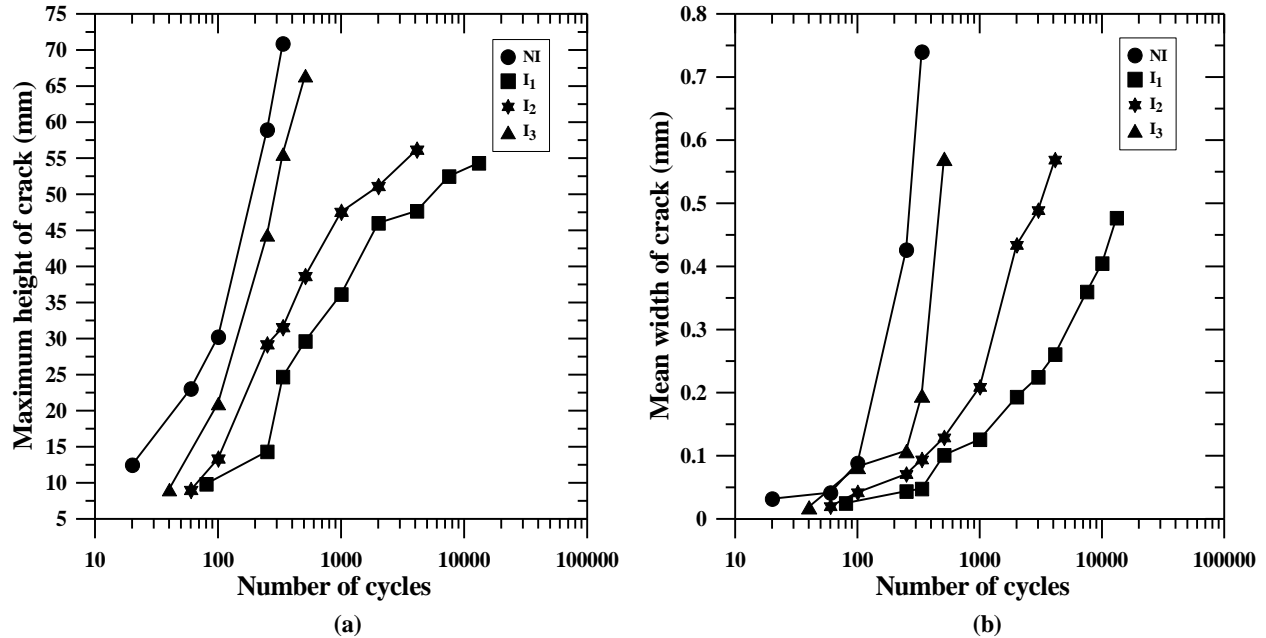


FIGURE 9 Crack initiation (Tensile strain contours) and failure of specimens (Tensile and vertical strain contours) (a) NI; (b) I₁; (c) I₂; and (d) I₃.

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2 **FIGURE 10** Variation of (a) mean crack width with number of cycles; (b) maximum crack
3 height with number of cycles
4

5 *Effect of interlayers*

6 The effect of interlayers on the flexural fatigue behavior of two layered asphalt beam specimens
7 can be evaluated with the help of tensile strain contours obtained from DIC analysis. Figure 9
8 shows the tensile strain contours for all the specimen configurations tested. It is observed that in
9 NI specimen, after the crack initiation, the tensile strains increase rapidly until the crack reaches
10 the overlay passing through the interface zone and fractures the specimen completely. Whereas,
11 in the specimens with interlayers (I_1 , I_2 and I_3), the tensile strains increase until the crack reaches
12 the interface zone and later the tensile strains are observed to be reduced because of the strain
13 relieving effect of the interlayers. The interlayers placed at the interface zone absorbs the stress
14 and restricts the further propagation of cracks into the overlays, whereas the crack propagation is
15 redirected and observed to propagate in the horizontal direction causing delamination of the old
16 and new pavement layers at the interface zone. However, with the inclusion of interlayers, the
17 fatigue life of two layered asphalt beam specimens are improved.

18 It is also observed that the propagation of cracks in the horizontal direction at the interface
19 zone has resulted in higher vertical strains in that zone. From Figure 9, it can be observed that the
20 vertical strains are accumulated at the interface zone for all the specimens with interlayers (b, c
21 and d). The accumulation of vertical strains at the interface zone further accelerates the
22 delamination of pavement layers by reducing their interface bond strength. A highest vertical strain
23 of 1.83 % is witnessed in the I_3 specimen, as their interface bond strength is very low (due to the
24 absence of apertures). The least vertical strain of 0.52 % was observed in the I_1 specimen, because
25 of a strong bond between the layers due to the presence of polymer modified binder coating on the
26 interlayer and the presence of aperture to encourage the through-hole bonding.
27
28
29
30

CONCLUSIONS:

A real field scenario of HMA overlays with and without interlayers placed on an existing old pavement was considered to study the flexural fatigue behavior of two layered asphalt beams using repeated load four-point bending test. The DIC technique was extensively employed to understand the behavior of asphalt beam specimens tested using flexural fatigue test and the following conclusions can be drawn:

The DIC technique is effective in detecting the crack evolution and their patterns, which helps to understand the flexural fatigue behavior of two layered asphalt specimens with and without interlayers. The technique provides detailed information about the crack openings and the corresponding deflections at each and every point in the area of interest, which cannot be provided by the conventional instrumentation (sensors and strain gages) as the prediction of crack distribution in advance is impossible.

The displacement fields obtained from DIC technique was accurate in providing the information about the vertical deformation of the two layered asphalt specimens. The mid-span vertical deformation values obtained from DIC technique correlated well with the values obtained from actuator sensor for all the test specimens at different load cycles.

The DIC results confirmed that the tensile strains are observed to be high after the crack initiation process and further propagates until the interface zone is reached. The DIC data depicted that the tensile strains are as high as 4.75% at the crack tip in the control specimens at 335 load cycles against 1.42% in a polyester grid interlayer at 13116 cycles. It is also observed that the crack initiation of two layered asphalt specimens took place within a vertical deformation value ranging from 1.5 mm to 3 mm, irrespective of the interlayer type.

An interlayer present at the interface zone restricts the further crack propagation by absorbing the high tensile stress coming from the cracks and redirects the cracks in the horizontal direction.

The asphalt beam specimens with interlayers performed well in improving the flexural fatigue life of the asphalt overlays compared to the control (NI) beam specimen. However, among the specimens with interlayers, I₁ specimen showed the highest improvement in the fatigue life.

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