1. INTRODUCTION

Most of the repair technology for the manhole raise due to the overlaid road pavement has been using concrete composite structures. The repair technology by using the concrete composite structures for manhole raise has been required in much construction work such as the assembling moulds, casting and aging. Recently, Seo et al. (2012) have developed an environmental-friendly manhole repair technology which can raise manhole to the regular height with rapid construction and minimum disruption to public traffic flow. But the manhole repair technology has been showing the structural problems such as around failure of the manhole raise due to the repeated truck load. In this study, the manhole repairing composite structures by using Fiber Reinforced Polymer (FRP) materials are considered as a potential solution to the repair problem of manhole due to the material’s superior properties, such as high strength or strength per unit weight, fast construction, easy installation and reduction of maintenance costs. (Son et al., 2012; CSA, 2002) FRP materials have recently been used in the area of civil engineering constructions (Son et al., 2013).

In order to resolve such problems, we have developed the new composite structures for the manhole raise by using a GFRP pipe. The technology can raise manhole to the regular height of the overlaid road pavement elevation with rapid construction, and...
minimum disruption to public traffic flow. This technology of manhole repair is method completed by double wide flanged GFRP pipe composite structures in order to raise manhole to the regular height. This flange member is made of methyl methacrylate monomer (MMA) resin mortar, composed of methyl methacrylate (MMA) resin, fine heavy calcium carbonic, and fine aggregate. The remarkable characteristics of MMA resin mortar are its high early strength, curing even in low temperature, and high abrasion resistance. The MMA resin is low viscosity, and flexible resin for use as a binder for polymer mortar (Omata et al., 1997; ACI, 2008a). The MMA resin is ideal for making flange member that will be connected to the GFRP pipe composite structures. However, due to the lack of data for performance and durability of the MMA double wide flanged GFRP pipe composite structures, it is not common practice for pavement engineers to use the MMA double wide flanged GFRP pipe composite structures to fix and raise manhole.


The main objective of this paper is to describe the structural behavior assessment of the MMA double wide flanged GFRP pipe composite structures subjected to axial loads based on an experimental investigation. The behavior assessments for this the MMA double wide flanged GFRP pipe composite structures are based on the axial load test, fatigue test, and ultimate load failure test. The assessment indicates that this technology for manhole raise by using the MMA double wide flanged GFRP pipe composite structures was confirmed safety, durability and reliability in result as expected. In this paper, we found that this environmental-friendly repair technology by using the MMA double wide flanged GFRP pipe composite structures was able to short working times to around 20% and construction costs to around 50% with compare other construction methods. Also, environmental pollution and civil complaints will be prevented because there will be no longer any noises, vibrations, dust, or construction wastes.

2. EXPERIMENTAL PROGRAM

To investigate structural characteristics of the proposed MMA double wide flanged GFRP pipe composite structures for a manhole raise construction in road pavement construction and to verify that the proposed MMA double wide flanged GFRP pipe composite structures meets all the design requirements, the following three different structural tests were conducted on the prototype MMA double wide flanged GFRP pipe composite structures: (1) axial load test; (2) fatigue load test to inspect the strength degradation; (3) ultimate load test to failure under static loadings.

2.1 Fabrication of specimens

The prototype MMA double wide flanged GFRP pipe composite structures sample was fabricated for conducting the axial load test, fatigue load, and ultimate load tests. The detailed drawing samples for the composite structures of manhole raise as shown in Fig. 1.
The proposed MMA wide doubled flanged GFRP pipe composites structures for a manhole raise (all dimensions in mm)

Fig. 1 were fabricated as following sequences: 1) manufacture of wide flanged tubular ring by using MMA resin mortar; 2) manufacture of composite structures with the GFRP pipe inserted the double wide flanged tubular ring; 3) manufacture of double wide flanged GFRP pipe composite structures filled with the cement mortar to the edge of ring.

The MMA double wide flanged GFRP pipe composite structures was fabricated as shown in Fig. 2.

The total of 9 specimens are fabricated. The specimens can be separated into 3 types: 1) double flanged, single-skinned GFRP pipe composite structure (type I) as shown in upper side of Fig. 6, 2) double flanged, doubled-skinned mortar filled GFRP pipe composite structure (type II) as shown in lower side of Fig. 6, 3) double flanged, single-skinned mortar filled GFRP pipe composite structure (type III) as shown in Fig. 3.

2.2 Experimental setup and instrumentation

2.2.1. Axial load test

Firstly, static axial load tests were conducted on the prototype MMA double wide flanged GFRP pipe composite structures sample. In case of the axial load test, a Servo electro-hydraulic actuator of a loading capacity of 1MN was used for the compressive tests under a range of loading. The axial load test setup for MMA double wide flanged GFRP pipe composite structures is shown in Fig. 4.
The MMA double wide flanged GFRP pipe composite structures test sample was tested under the axial loading. The static load was applied to the composite structures through a $844mm \times 844mm$ steel loading frame as shown in Fig. 5.

A steel loading frame was placed on the composite structures so as to apply force from actuator and have that force transmitted to the steel loading frame at center. Six MMA double wide flanged GFRP pipe composite structures specimens were tested. Load, deflection and strain were the general measurements in this experimental program. The displacement using linear variable deflection transducers (LVDTs) at two points along the midsection and strains using strain gauges at the outer face, and inner of the specimen were measured as shown in Fig 6.

The location of strain gauges are at the outer face of the specimen (O1, O2, O3, O4), and the inner face (I5, I6, I7, I8) and the location of LVDTs at two points along the midsection represented by D1, D2 at outside of GFRP surface at half diameter are shown in Fig. 7.

2.2.2. Fatigue load test

Secondly, MMA double wide flanged GFRP pipe composite structures should consider the effects of fatigue loading. In order to evaluate the fatigue...
resistance of the MMA double wide flanged GFRP pipe composite structures’ predicted service life, a fatigue loading test was performed. The load was applied using a Servo Fatigue electro-hydraulic actuator permanently fixed to a framework. The Servo Fatigue electro-hydraulic actuator had a loading capacity of 1MN like the static axial load test. This test was controlled using a digital servo controller. A digital controller was used to control the load range, frequency of loading and the number of cycles of the hydraulic actuator. The fatigue load test setup for MMA double wide flanged GFRP pipe composite structures is shown in Fig. 8.

The number of cycles for fatigue load test are 0.5 million. Two MMA double wide flanged GFRP pipe composite structures specimens were tested. The locations of displacement, and strain measurement are same to the axial load test.

2.2.3. Ultimate load test
Finally, in case of the ultimate load test, a UTM of a loading capacity of 5MN was used for an ultimate load test. The ultimate load test was to examine the failure strength and failure progression. The specimen for the ultimate load test was fabricated in the double wide flanged GFRP pipe composite structures filled with the cement mortar to the edge of ring as shown in Fig. 3. The ultimate load test setup for MMA double wide flanged GFRP pipe composite structures is shown in Fig. 9.

The displacement using linear variable deflection transducers (LVDTs) at two points along the midsection and strains using strain gauges at the outer face of the specimen were measured as shown in Fig 10.

Fig. 10 Location of LVDTs and strain gauges

2.3 Experimental procedure and results

2.3.1. Axial load test
The test samples were preloaded up to 100 kN at a
loading rate of 2.2 kN to 4.4 kN per minute and then released. The test specimens were loaded in the cycle three times at regular intervals. This operation was to ensure the loading edges, remained in proper contact with the test specimen. The first step of axial load test was a design load test for observing behavior of the MMA double wide flanged GFRP pipe composite structures up to the truck wheel load 122.3 kN, which 94.08 (kN) plus a 30% impact allowance (MOCT, 2002), and followed by a load up to 903 kN due to the hydraulic actuator with load capacity of 1,000 kN. Table 1 shows the comparison of displacement and strain of specimens in type I, not to be filled with a mortar.

### Table 1. Displacements and strains from axial load test (load=122.3kN) in Type I

<table>
<thead>
<tr>
<th>Load cycling (cycles)</th>
<th>Mid-height lateral deflection (mm)</th>
<th>Mid-height transverse strain (micro strain)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left centerline D1</td>
<td>Right centerline D2</td>
</tr>
<tr>
<td>Specimen 1</td>
<td>0.07</td>
<td>0.04</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>0.04</td>
<td>0.01</td>
</tr>
<tr>
<td>Specimen 3</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>Mean value</td>
<td>0.08</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 2 shows the comparison of displacement and strain of specimens in type II, to be filled with a mortar.

### Table 2. Displacements and strains from axial load test (load=122.3kN) in Type II

<table>
<thead>
<tr>
<th>Load cycling (cycles)</th>
<th>Mid-height lateral deflection (mm)</th>
<th>Mid-height transverse strain (micro strain)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left centerline D1</td>
<td>Right centerline D2</td>
</tr>
<tr>
<td>Specimen 1</td>
<td>0.09</td>
<td>0.09</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>0.06</td>
<td>0.14</td>
</tr>
<tr>
<td>Specimen 3</td>
<td>0.23</td>
<td>0.01</td>
</tr>
<tr>
<td>Mean value</td>
<td>0.13</td>
<td>0.08</td>
</tr>
</tbody>
</table>

The performance criteria for strength for the MMA double wide flanged GFRP pipe composite structures was based on the allowable strength criteria. The displacement at the mid-height of the column was 0.35mm at the service load 902.8 kN. The load-displacement curve up to 900 kN is shown at two points along the mid-height of the column in Fig. 11.

After unloading from the applied load of 903 kN, some residual displacement was not observed. The load-strain curve up to 900 kN at location of the outer face of the specimen (O3), and the inner face (I7) is shown in Fig. 12, and Fig. 13.

The strain at location of the outer face of the
specimen (O3) is recorded about 111 με in the load of 122.3 kN of the standard truck wheel load [12]. The strain at location of the inner face of the specimen (I7) is recorded about 158 με in the load of 122.3 kN. The stresses calculated from this strains was from 3.6 MPa in the inner face of the specimen, and 5.2 MPa in the outer face of the specimen. These strains are less than the allowable strain, 20% of maximum strain of the FRP coupon test, 3930 με in the GFRP pipe made by the HANKUK FIBER GROUP (2004).

2.3.2. Fatigue load test

The MMA double wide flanged GFRP pipe composite structures should consider the effects of fatigue loading. In order to evaluate the fatigue resistance of the MMA double wide flanged GFRP pipe composite structures' predicted service life, a fatigue loading test was performed. A manhole on road pavement should carry over 0.5 million vehicles for more than 3-year according to Korea standards specifications (MOCT, 2002). The load was applied using a Servo electro-hydraulic actuator permanently fixed to a framework. The actuator had a loading capacity of 1000 kN. This test was controlled using a digital servo controller. A digital servo controller was used to control the load range, frequency of loading and the number of cycles of the hydraulic actuator. A spreader box of a 844mm × 844mm steel loading frame was utilized to apply the load at the top flanged GFRP pipe composite structures. This spreader box of a steel loading frame was supported by the top flanged GFRP pipe composite structures. This the top flanged GFRP pipe composite structures sample was subjected to fatigue loading for 500,000 cycles that may represent years of actual service for a manhole. The load was cycled between the maximum load of 150 kN and the minimum load of 30 kN at a frequency of 3Hz under load control. The loading cycles simulate passage of the rear axle load of a standard truck including impact factor 1.3, which is 122.4 kN (MOCT, 2002). In the case of fatigue test, each test sample was instrumented with both strain gages and displacement transducers. The deflection, strain for the test sample were recorded during the test using a high-speed data acquisition system.

The static tests were conducted on the test sample after 500,000 cycles of the fatigue load test. The load-displacement curves, and load-strain curves at several composite structures' locations during the static tests after 0.5 million cycles were shown in Fig. 14, and 15.

![Fig. 14 Load-displacement response after fatigue cycling (500,000)](image)

![Fig. 15 Load-strain response after fatigue cycling (500,000)](image)

From the results the deflection and strain response remained fairly constant for all of the axial load tests, and the MMA double wide flanged GFRP pipe composite structures was shown no apparent changes in strength of the structure. And deterioration of the MMA double wide flanged GFRP pipe composite structures caused by the fatigue loading was not inspected at composite structures. From the inspection, no visible signs of deterioration to the MMA double wide flanged GFRP pipe composite structures and
MMA resin mortar ring were observed. A comparison of displacement, and strain measurements for the axial load test conducted after 500,000 fatigue cycles are shown in Fig 16, and 17.

The mid-height displacement at 150kN for test after fatigue cycling was 0.04mm and the maximum measured strain at GFRP pipe of the mid-height was 1918 $\mu$e in the loading direction.

![Fig. 16 Comparison of load-displacement between static load test and fatigue load test](image1)

![Fig. 17 Comparison of load-strain between static load test and fatigue load test](image2)

<table>
<thead>
<tr>
<th>Load cycling (cycles)</th>
<th>Mid-height lateral deflection (mm)</th>
<th>Mid-height transverse strain (micro strain)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left centerline D1</td>
<td>Right centerline D2</td>
</tr>
<tr>
<td>0</td>
<td>0.09</td>
<td>0.04</td>
</tr>
<tr>
<td>500,000</td>
<td>0.10</td>
<td>0.04</td>
</tr>
</tbody>
</table>

### 2.3.3. Ultimate load test

An ultimate load test for the MMA double wide flanged GFRP pipe composite structures was conducted for observing the ultimate load capacity and failure mode of the column was loaded up to 4MN using a hydraulic actuator with the load capacity of 5MN. The load-displacement, and load-strain curves are shown in Fig. 18, and 19.

![Fig. 18 Load-displacement response from ultimate load test](image3)

![Fig. 19 Load-strain response from ultimate load test](image4)
Table 4 shows comparison of displacement and strain for the specimens at ultimate load test. As loading was continued, displacement to a full load of 5MN became linear, and no sign of failure was obtained. The strain was increased linearly to around the load of 2.2MN, and the strain is showing about $1679 \mu \varepsilon$. After at that load, the strain values were decreased sharply. The failure of the filled mortar was resulted in the MMA double wide flanged GFRP pipe composite structures.

<table>
<thead>
<tr>
<th>Load cycling (cycles)</th>
<th>Mid-height lateral deflection (mm)</th>
<th>Mid-height transverse strain (micro strain)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Left centerline D1</td>
<td>Right centerline D2</td>
</tr>
<tr>
<td>Specimen 1</td>
<td>0.170</td>
<td>0.300</td>
</tr>
<tr>
<td>Specimen 2</td>
<td>0.395</td>
<td>0.365</td>
</tr>
<tr>
<td>Specimen 3</td>
<td>0.055</td>
<td>0.150</td>
</tr>
<tr>
<td>Mean value</td>
<td>0.207</td>
<td>0.272</td>
</tr>
</tbody>
</table>

2.3.4. Strength capacity, stiffness, and axial ductility

The total of 3 types specimens are tested as following: 1) double flanged, single-skinned GFRP pipe composite structure (type I), 2) double flanged, doubled-skinned mortar filled GFRP pipe composite structure (type II), 3) double flanged, single-skinned mortar filled GFRP pipe composite structure (type III). Comparison of strength capacity, and stiffness for each type described above was shown in Table 5.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>$P_u$(kN)</th>
<th>$\varepsilon_p$(µε)</th>
<th>$E_{comp}$(MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type I</td>
<td>902.8</td>
<td>2,955</td>
<td>14,455</td>
</tr>
<tr>
<td>Type II</td>
<td>897.7</td>
<td>2,296</td>
<td>42,800</td>
</tr>
<tr>
<td>Type III</td>
<td>2,182.2</td>
<td>1,678</td>
<td>40,028</td>
</tr>
</tbody>
</table>

The strength capacity $P_a$ of the double wide flanged GFRP pipe composite structures is defined as the peak value of the axial loads observed in the axial loads-strain curve. The value of $P_a$ is the nominal strength given as following:

$$P_a = A_f f_{y, f} + A_c f_c$$  \hspace{1cm} (1)

where $A_f$ and $A_c$ are the cross-sectional areas of the GFRP pipe and resin mortar section, respectively. The $f_{y, f}$ and $f_c$ are the yield strength of the GFRP pipe and the actual compressive strength of mortar.

The initial stiffness $E_{comp}$ of the double wide flanged GFRP pipe composite structures is defined as the averaged initial slope of an axial load-strain curve. It is calculated from its linear recurrence within the range of axial deformation, divided by the cross-sectional area $A_{total}$ of the double wide flanged GFRP pipe composite structures. The double wide flanged GFRP pipe composite structures stiffness, according to the theory of superposition can be expressed as following:

$$E_{comp} = \frac{(A_f E_1 + A_c E_c)}{A_{total}}$$  \hspace{1cm} (2)

where $A_f$ and $A_c$ are the cross-sectional areas of the GFRP pipe and resin mortar section, respectively. The $E_1$ and $E_c$ are the young's modulus of lamina of FRP member, and resin mortar. The stiffness properties of a lamina can be calculated by the micro-mechanics models based on several simple rules of mixtures, as shown below:

$$E_1 = \eta_o E_f V_f + E_m (1 - V_f)$$  \hspace{1cm} (3)

where $\eta_o$ = efficiency factor of the fiber. For unidirectional fibers, $\eta_o=1.0$; bi-directional fibers, $\eta_o=0.5$; random in-plane fibers, $\eta_o=0.375$. $E_f$, $E_m$ =Young’s modulus of the fiber and matrix; $V_f$= fiber volume fraction for each lamina. And the resin mortar is calculated from $E_r = 4733 \sqrt{f_c}$ MPa.

From Table 10, it is observed that the strength the type III specimen is the highest of the all types specimens, but there is showing the strength between the type I and type II. As shown in Table 10, the type II is the highest stiffness of the three types. The type III specimen was fabricated with considering construction work for the manhole raise on the road pavement.
3. FINITE-ELEMENT MODEL

A Finite Element (FE) analysis by ANSYS (2005) was carried out for the test of the MMA double wide flanged GFRP pipe composite structures sample. The MMA double wide flanged GFRP pipe composite structures were modeled by 8-node shell elements, while the MMA resin mortar ring was modeled by solid elements. The adhesive bonds between the GFRP pipe and the wide flange ring were assumed in the model as rigid connections. The overall FE model for the test specimen is shown in Fig. 24.

![Fig. 20 FE model of the specimen (ANSYS)](image)

The boundary conditions in axial load test were modeled as a fix for the end support. The boundary conditions at nodes of the MMA double wide flanged GFRP pipe composite structures were modeled as constrained displacement in the vertical direction. The layer stiffness properties of laminates of GFRP pipe are calculated by a simple rule of mixtures approach from micro-mechanics models.

The FE analysis comparisons of displacement and strength results at a load of 122.3 kN are shown in Tables 6.

![Fig. 21 Displacement of the specimen (ANSYS)](image)

![Fig. 22 Strength of the specimen (ANSYS)](image)

<table>
<thead>
<tr>
<th>Lateral displacement (mm)</th>
<th>Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experiment (mean value)</td>
<td>0.08</td>
</tr>
<tr>
<td>Analysis (ANSYS)</td>
<td>1.13</td>
</tr>
</tbody>
</table>

The displacement and strength of the MMA double wide flanged GFRP pipe composite structures are compared at the maximum design load, 122.3 kN. Generally, the test results are higher than those of the analysis, but the displacement computed at 122.3 kN was 32 % less than those measured during the tests as shown in Table 6. As the primary reason, the load transferred from the flange member was not seemed loaded the GFRP pipe through the connection between the flange and pipe unlike the FE analysis. The predicted yield load was considered as over 900 kN. Fig. 21, and 22 are shown the displacement, and strain of the MMA double wide flanged GFRP pipe composite structures by ANSYS.

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4. EVALUATION OF MMA DOUBLE WIDE FLANGED GFRP PIPE COMPOSITE STRUCTURES PERFORMANCE

The results of the three different tests performed on the prototype of the MMA double wide flanged GFRP pipe composite structures sample were used to determine characteristics of the full-size MMA double wide flanged GFRP pipe composite structures. The test sample is not failed at over 900 kN, which is of the order of eight times the design standard wheel load. This indicates extremely good performance of the MMA double wide flanged GFRP pipe composite structures as far as strength is concerned. The mid-height displacement of the MMA double wide flanged GFRP pipe composite structures sample at the design wheel load were 0.35mm and 0.26mm for the static load test before fatigue loading and the post-fatigue load test. The strength after the fatigue loading test was higher than the static load test as shown in Table 8. It was found that the strength of the proposed MMA double wide flanged GFRP pipe composite structures in this study was within the allowable value in the manhole's column.

It also found that this technology of manhole by using the proposed MMA double wide flanged GFRP pipe composite structures was able to short working times to around 30-50% and construction costs to around 10-23% with compare other construction methods as shown in Table 7. Also, environmental pollution and civil complaints will be prevented because there will be no longer any noises, vibrations, dust, or construction wastes.

<table>
<thead>
<tr>
<th>Company</th>
<th>Cost(₩)</th>
<th>Construction times(min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>685,687</td>
<td>90</td>
</tr>
<tr>
<td>B</td>
<td>774,314</td>
<td>100</td>
</tr>
<tr>
<td>C</td>
<td>658,238</td>
<td>120</td>
</tr>
<tr>
<td>Developed method</td>
<td>594,479</td>
<td>60</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

The behaviour of the proposed MMA double wide flanged GFRP pipe composite structures for manhole raise was evaluated using an experimental approach. Based on the study presented in this paper, The MMA double wide flanged GFRP pipe composite structures can meet the strength design criteria as defined in the specifications of the manhole. It was found that the strength criteria for the MMA double wide flanged GFRP pipe composite structures may be presented in terms of allowable strain for the FRP composites and allowable stress for MMA resin materials. The failure load of 900 kN was eight times the design wheel load of 122.3 kN. No reduction in strength or strength was found after 500,000 cycles of fatigue load in the design wheel load. The MMA double wide flanged GFRP pipe composite structures met the service load design criteria after fatigue cycling. The proposed technology of the MMA double wide flanged GFRP pipe composite structures for manhole raise was able to not only improve strength but also be cost-efficient compared to other technology of manhole raise. The use of MMA double wide flanged GFRP pipe composite structures utilizing materials in a combination favourable to the individual component's strengths and characteristics was shown.

ACKNOWLEDGMENT

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