BEHAVIOR AND DUCTILITY OF STRENGTHENED WITH EXTERNAL USING LIFTING HOLE ANCHORAGE SYSTEM

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ABSTRACT: Since various methods for repairing and rehabilitating have been applied to damaged bridges to increase their load carrying capacity, many researches on the methods have been widely carried out. In particular, In terms of applicability, strengthening efficiency and economical efficiency, external tendons using lifting hole anchorage system is the most effective method among the aforementioned methods. In order to verify the strengthening effectiveness, flexural experiments on the beams strengthened with external tendons using lifting hole anchorage system were carried out. The experiments were conducted on two groups of systems, the existing and the proposed external tendons using lifting hole anchorage system. In addition, An evaluation on ductility of the beams were conducted in this paper.

Keywords: Lifting hole, External tendon, Load carrying capacity, Energy method, Ductility

1. INTRODUCTION

The technology of post-tensioning of a concrete bridge can be used to increase the load-carrying capacity of existing bridges. Economical and technical application of post-tensioning has been widely used for concrete bridges. There have also been some applications of the post-tensioning method by prestressing force for performance improvement of steel and timber bridges (Han, 2005).

The methods for repairing and rehabilitating reinforced concrete (RC) and prestressed concrete (PSC) bridges in Korea include the sole plate reconstruction method, the steel plate method, the externally-bonded FRP method and the external tendon method (Park, 2005). Of these, the external tendon method is frequently used to strengthen various concrete structures because of its high applicability and strengthening efficiency. The external tendon method has many advantages that can ensure easy structural analysis and big economical feasibility (Naaman, 2004). Furthermore, because of the light weight of the strengthening material, the bridges do not have to carry any additional load. In addition, installation is simple and the construction period is short (TRB, 1997). After construction, the structure can be maintained easily and stress can be handled by adjusting the prestressing force (AASHTO, 1998).

Although the external tendon method has no serious problems for the strengthening performance or for the analysis method of concrete structures, various problems arise when the anchorage elements installed to set the tendons didn't have an acceptable capacity (Ghallab, 2005; Aparicio, 2002; Miyamoto, 2000) example, the resisting capacities of the existing anchorage element for the prestressing force are very low. It is an undesirable thing. The existing structure will be inevitably damaged when the anchorage elements were installed and design of the anchorage elements is impossible because of complicated stress transfer mechanism.

In this study, the author suggests the jacket-based anchorage element (JBAE) using lifting hole, which is a kind of bearing support method. We compare it with the existing lifting-hole anchorage element (LHAE), which is a used in existing construction. The comparative items included the cracking load, the yielding load, the ultimate load, the failure phase. In addition to the evaluation on the load carrying capacity, an evaluation on ductility of the beams were conducted in this paper. Since the failure modes of the strengthened or repaired structures tend to be brittle, not only the research on the strengthening effectiveness but also ductility is necessary. By using the energy method, ductility of the beams, which were strengthened with the external tendons using lifting hole anchorage systems were evaluated and they were analyzed.

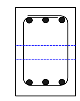
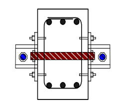
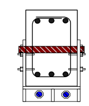
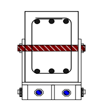
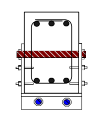
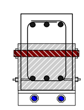
2. EXPRIMENT PROGRAM

2.1 Test variables

The flexural performance was evaluated by comparing the anchorage elements of the LHAE and the JBAE using lifting-hole.

Ten beams were made, as shown in Table 1, for the static loading tests: one standard beam without anchorage element, three beams with the LHAE and six beams with JBAE. The strengthened beams except the ED1 have a same size of 3300×450×300, same eccentricity of 280mm and same strand profile of straight. Moreover, pre-stressing force was applied to a steel bar of ESM1 series and ESM2 series to observe the subsequent reaction.

Table 1. Test variables

Beam type		f_{ck} (MPa)	Eccentricity (mm)	Jacking force (kN)		Strand profile	Size (mm)	Anchorage shape
				Strand	Bar			
Standard	ST							
Lifting-hole anchorage element	ED1		140	190		Draped		
	ES1		280	95		Straight		
	ES2	30	280	95		Straight	3300 ×450 ×300	
Jacket-based anchorage element	ESM1		280	95	0	Straight		
	ESM1-5		280	95	50	Straight		
	ESM1-10		280	95	100	Straight		
	ESM2		280	95	0	Straight		
	ESM2-5		280	95	50	Straight		
	ESM2-10		280	95	100	Straight		

.2 Material properties

The ready-mixed concrete indicated in Table 2 was used to make the test specimens. The average value of concrete compression strength was 30 MPa. A deformed bar of HD40 was used according to KSD3504. D10, D13 and D16 were used respectively. To introduce the prestressing force, a strand of SWPC was used, which was a B type with seven lead wires stipulated in KSD 7002 and the dywidag steel bar was used. To make the anchorage elements, SM490 steel plate with a thickness of 10 mm was used in accordance with KSD3515 (rolled steel for a welded structure). Table 2 shows the relevant material properties of the test materials.

2.3 Fabrication

Fig. 1 shows the anchorage elements of the JBAE and the LHAE. In the case of the LHAE(ED1, ES1, ES2), the applied prestressing force is supported by the shear force of the anchor bolt and the steel bar for the lifting-hole. Eight anchor bolts with an allowable shear force of 27 kN was used and the resulting allowable load-carrying capacity was approximately 210 kN. In the case of the JBAE (ESM1 Series, ESM2 Series), the applied prestressing force is supported by the welding force from the edge plate and the steel bar for the lifting-hole. Six anchor bolts with an allowable shear force of 27 kN was used. To the floor plate and the anchorage plate, the thickness of the welding is 6 mm and the welding strength for the length of the unit is approximately 2.9 kN. The total allowable load-carrying capacity is 162 kN

Table 2. proportion of the materials

Concrete

Cement (kN/m^3)	Water (kN/m^3)	Fine aggregate (kN/m^3)	Coarse aggregate (kN/m^3)	Chemical agent (kN/m^3)	W/C (%)
10.28	4.63	19.56	25.54	30.85	42

Reinforceing bar

Type	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
D10	409	637	20.0
D13	454	621	21.0
D16	485	601	22.3

PS strands

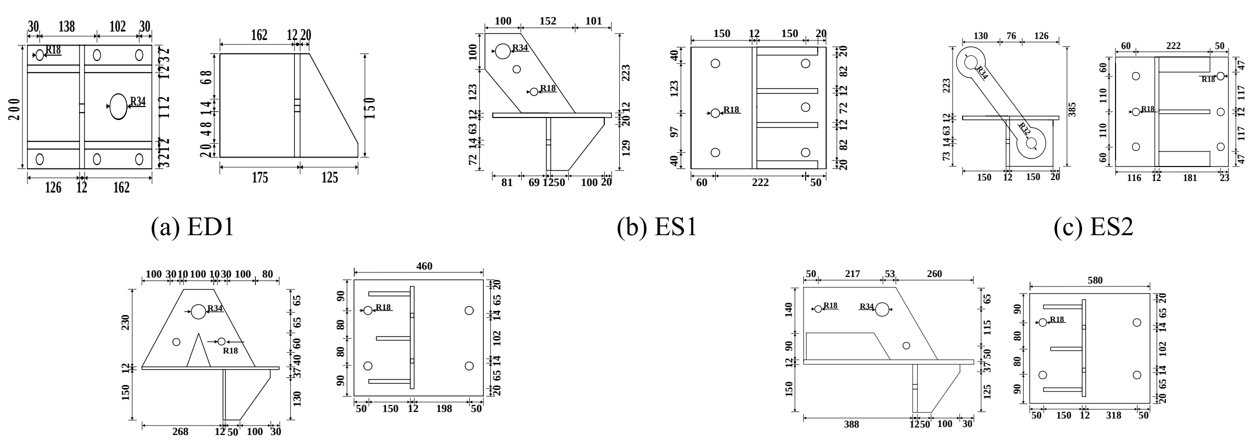
Type	Diameter (mm)	Area (mm^2)	Tensile load (kN)	Extensibility (%, more than)
SWPC7B	12.7	98.7	183.4	3.5

PS steel bar

Diameter (mm)	Yield load (kN)	Tensile load (kN)	Max. jacking load (kN)
34	671	828	804

Steel plate

Yield strength (MPa)	Tensile strength (MPa)	Allowable compressive stress in bending (MPa)	Allowable shear stress (MPa)	Bearing stress
313.8	480.3~588.4	186.3	107.9	274.6



(a) ED1 (b) ES1 (c) ES2

(d) ESM1 Series (e) ESM2 Series

Figure 1. Details of anchorage elements (unit : mm)

Based on the structural standard of the Korea Concrete Institute (KCI, 2003), All beams was made in accordance with the ultimate strength design and as a rectangular double reinforcement beam with the following dimensions: cross-section of 300 mm x 450 mm, compressive bars of 3-D13, tensile bars of 3-D16, total length of 3,300 mm and effective span of the beam of 3,000 mm.

The shear bars of D10 was arranged intervals of 150 mm. The reinforcing bar was arranged below a balanced steel ratio. Fig. 2 shows the shapes of each beam.

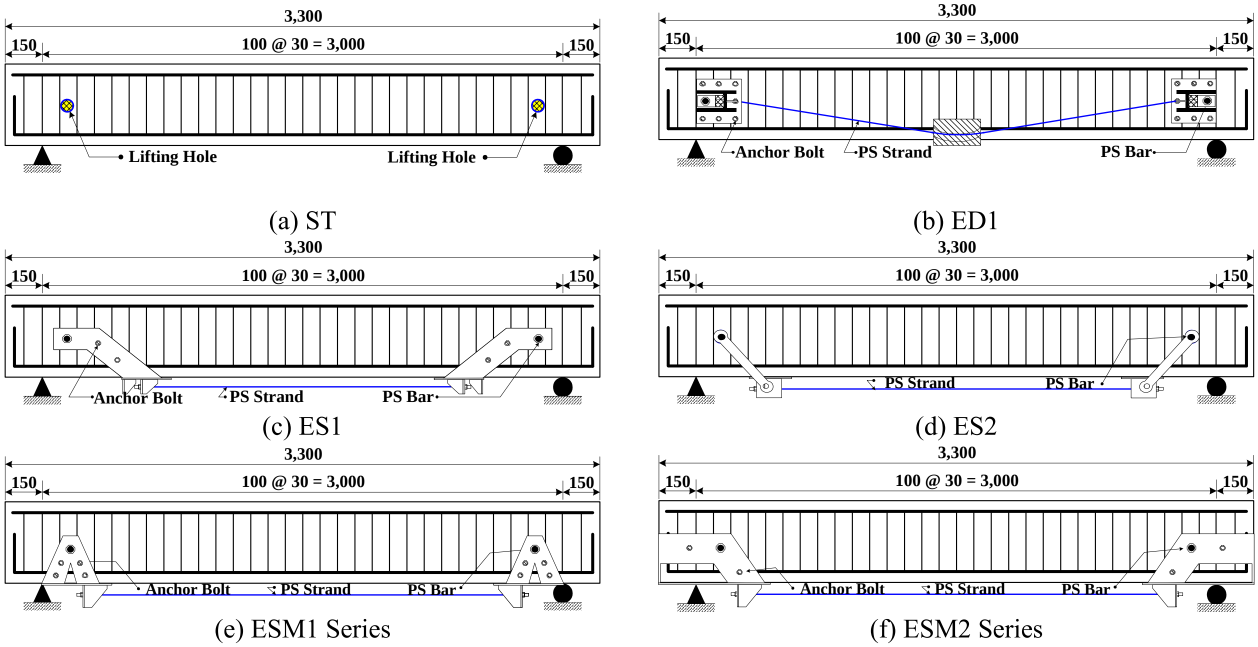


Figure 2. Details of each specimen (unit : mm)

2.4 Loading and instrumentation

All beams were tested with four-point bending using 980 kN UTM device as shown in Fig. 3. The Loading was performed through the displacement control with a rate of 0.05mm/sec. The tests were finished after failure and the beam was unloaded. Measurements on each specimen were achieved using static data logger and computers, and were measured in 1 second intervals. LVDT was installed in the L/4 position and the center to measure the displacement of the specimen. To measure the strain, electric resistance strain gauge (measurement limit: 15,000με) has been layed in the mid-span and the load position of the tensile and compressing steel, and concrete gauge has been attached in the upper, middle and lower position. Furthermore, strain gauge was attached to the anchorage element to measure the deformation of the anchorage by the loading

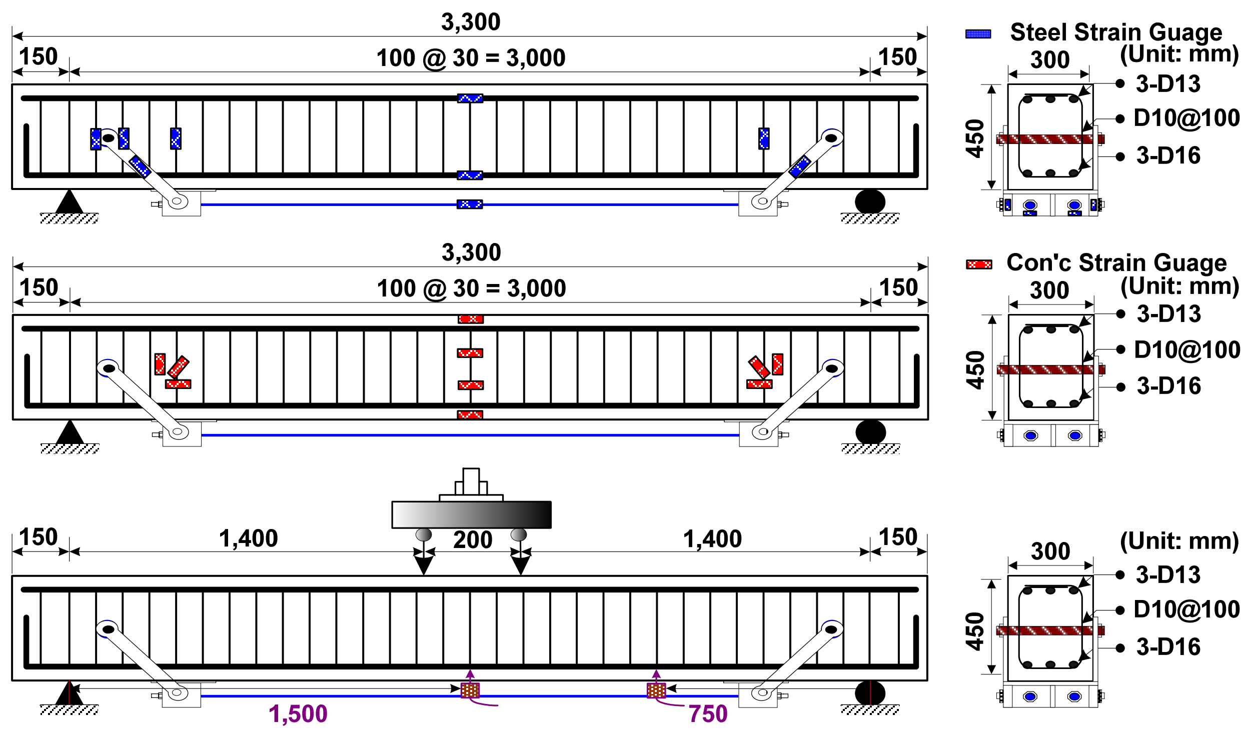
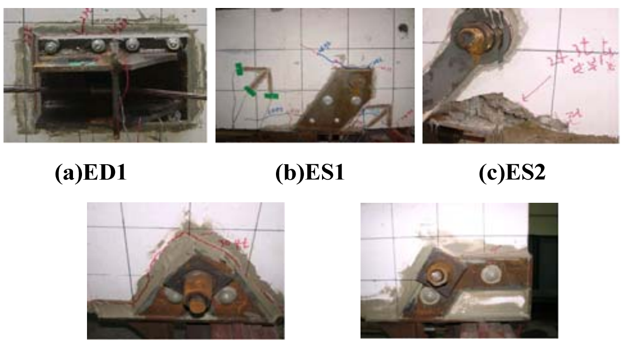


Figure 3. Installation of the gauges and LVDTs (unit : mm)

3. Test results and discussion

3.1 Failure modes

In Fig. 4, all beams, including the standard beam, showed flexural failure. Flexural crack developed in all beams and as the cracking load increased, the crack length increased. After the yielding of the reinforcing bar, the width of the crack increased. All reinforced beams showed increased load resistance and less displacement and more stiffen than the standard beam (ST) under at the same load. However, brittle failure, as shown in Fig. 4 was occurred in anchorage elements of ED1, ES1 and ES2. But epoxy falling off was only occurred in anchorage elements of ESM1 series and ESM2 series.



(a)ED1 **(b)ES1** **(c)ES2**

(d)ESM1 Series **(d)ESM2 Series**

Figure 4. Failure modes of the anchorage element

3.2 Load-Displacement

Fig. 5 shows the load- displacement curve of the strengthened beams comparing with that of the standard beam. With respect to the yielding load of each beam, the reinforcing bar yielded at 55 kN in the ST beam. The yielding loads for ED1, ES1 and ES2 beams with external prestressing of 95 kN and 190 kN increased about 41%, 88% and 69%, respectively.

The yielding loads for ESM1series and ESM2series beams with external prestressing of 95 kN, which have not the same prestressing force for steel bar, increased about 100% ~ 117% and 110% ~ 148%, respectively. These results show that newly proposed anchorage element is very effective to stand to the yielding load.

ED1, ES1 and ES2 beams showed a strengthening effect based on the ultimate load of approximately 66%, 86% and 63%, respectively. ESM1series and ESM2series beams showed approximately 78% ~ 114% and 131%~136%, respectively. However, the strengthened beams using LHAE clearly showed a mode of brittle failure, in which the compressive region of concrete was radically destroyed at the ultimate load. But the strengthened beams using JBAE showed a mode of ductile failure.

The maximum displacement at the ultimate load for the ST beams was approximately 67.9mm. For the strengthened beams using the LHAE, they were as follows: ED1, 34.9 mm; ES1, 32.5 mm; ES2, 25.4 mm. For the strengthened beams using the JBAE, they were as follows: ESM1series, 52.7 mm ~ 57.2 mm; ESM2series, 56 mm ~ 57 mm. This result means that when external tendons are used, the maximum displacement at the ultimate load is less than that of the ST beam. But the strengthened beams using JBAE showed more ductile than the strengthened beams using the LHAE, less than the ST beam.

In Table 3, The significant loads of all specimens with comparisons of strengthen effects are presented (cracking, yielding of steel reinforcing bar, and ultimate loads), the result show that both and increased cracking and steel yielding load can be achieved by strengthening with jacket-based anchorage element (JBAE) using lifting hole and existing lifting-hole anchorage element (LHAE).

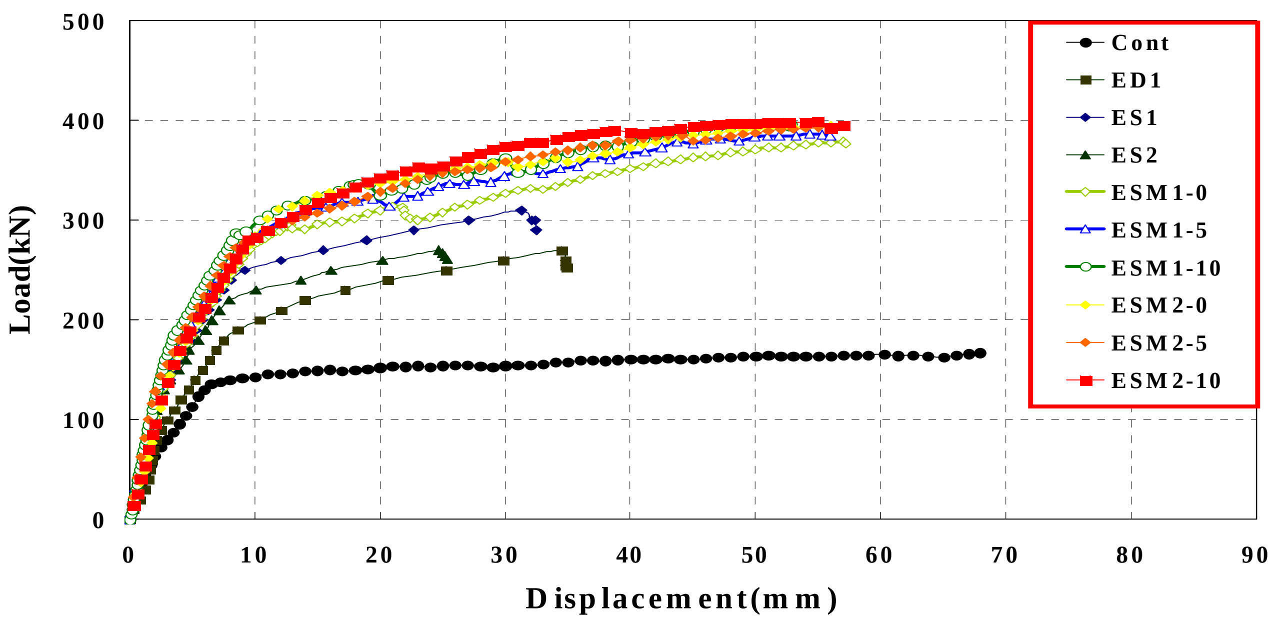


Figure 5. Relationship between load and displacement

Table 3. Comparisons of important values for loads

Beam type		Cracking load (kN)	Yielding load (kN)	Ultimate Load (kN)	$Strengthing\ effect(\%) = (\frac{RIF}{STD} - 1) \times 100$	
					Yielding (%)	Ultimate (%)
Standard	ST	55	133	167	0	0
LHAE	ED1	97	187.5	277.5	41	66
	ES1	118	251	310.5	88	86
	ES2	115	225	272	69	63
JBAE	ESM1	105	267	297	100	78
	ESM1-5	120	275	335	107	101
	ESM1-10	138	288	357	117	114
	ESM2	118	280	386	110	131
	ESM2-5	132	299	390	122	133
	ESM2-10	150	325	394	148	136

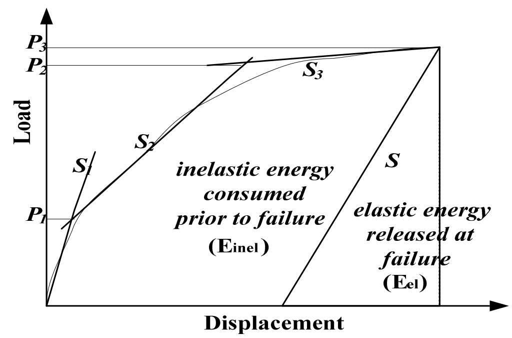
3.3 Evaluation of the ductility index

Ductility is a qualitative concept that refers to inelastic deformation. It indicates the state of a material, namely that of a structural section, a structural member or a structural system, before the material collapses without notable loss of resistance. Ductility can be regarded as an important safety factor that delays local failure by redistributing the overstress of a critical section to another section of a statically indeterminate structure. The ductility index, or the ductility factor used to measure ductility, is the ratio of curvature, rotation or deflection as defined by the following equation:

$$\mu_\phi = \frac{\phi_\mu}{\phi_y}, \quad \mu_\theta = \frac{\theta_\mu}{\theta_y}, \quad \mu_\Delta = \frac{\Delta_\mu}{\Delta_y} \qquad \text{(Eq. 1)}$$

where μ : ductility index of a member
ϕ : rotation factor of a member
θ : curvature of a member
Δ : deflection of a member.

In Eq. 1, two significant reference points are needed: yield point and ultimate point. However, there is no general agreement on what these points should be. Yielding of the prestressing steel in a prestressing beam is not well defined, while yielding of the reinforcing bar in a reinforced concrete beam can be precisely defined. So a proposed ductility index (Grace, 1998), as shown in Eq. 2, was used to evaluate the strengthened beams.



$$E_{tot} = E_{inel} + E_{el}$$

$$S = \frac{P_1 S_1 + (P_2 - P_1) S_2 + (P_3 - P_2) S_3}{P_2}$$

S, S_1, S_2, S_3 : slope

Figure 6. New definition of ductility index (grace, 1998)

$$ER = \frac{E_{inel}}{E_{tot}} \qquad \text{(Eq. 1)}$$

The ductility indices for the member displacement of the ten test beams were computed using newly proposed ductility index in Eq. 2, and tabulated in figure 7 and Table 4.

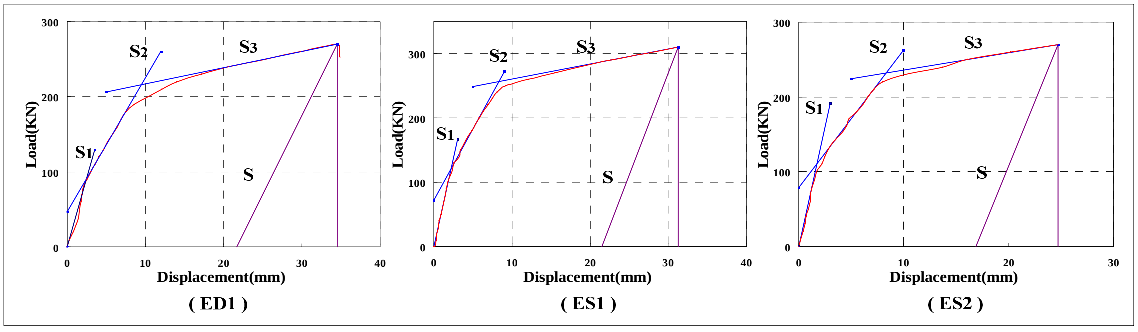


Figure 7. Evaluation of ductility index

Table 4. Comparisons of ductility index

Beam type		S	E_{inel} (kN·mm)	E_{tot} (kN·mm)	ER (E_{inel} /E_{tot})	Clas.
Standard	ST	22.5	9559	10179	94%	Ductile
LHAE	ED1	20.8	5510	7258	76%	Ductile
	ES1	26.8	5928	7721	80%	Ductile
	ES2	35.0	4115	5279	79%	Ductile
JBAE	ESM1-1	28.4	14905	17430	86%	Ductile
	ESM1-2	33.2	14969	17221	87%	Ductile
	ESM1-3	35.3	14736	16955	87%	Ductile
	ESM2-1	28.2	15456	18223	85%	Ductile
	ESM2-2	32.5	15522	17897	87%	Ductile
	ESM2-3	29.2	15504	18231	85%	Ductile

8. CONCLUSIONS

Ten beams have been tested, 3 with existing lifting-hole anchorage element and 6 with jacket-based anchorage element using lifting hole for strengthening. The results from the tests show that the proposed anchorage element using lifting hole is an efficient method to transfer prestressing forces between the tendon and concrete. The problems with brittle failure of the anchorage elements, which were a problem when existing lifting-hole anchorage element, are minimized with the use of jacket-based anchorage element using lifting hole.

1) The tests show a large increase in the crack and reinforcing bar yielding load. The increase in load for reinforcing bar can be very significant for the lifetime of an infrastructure. The fatigue behavior will be improved and as a consequence the crack width will be smaller, which can result in increased durability

2) With strengthened by external prestressing through the anchorage element of jacket based using lifting hole, the shear force at the edge diminished more than that of the beams of the anchorage element of existing lifting-hole. Therefore, brittle failure at the edge is not expected in actual use.

3) The results from the tests show that when external tendons are used, the maximum displacement at the ultimate load is less than that of the standard beam. But the strengthened beams with jacket-based anchorage element using lifting hole showed more ductile than the strengthened beams with existing lifting-hole anchorage element, less than the ST beam.

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