Development of a double-tee flange connection using shape memory alloy rods

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- The goal of this study was to develop a durable flange-to-flange connection for double-tee beams using shape memory alloy rods.
- Previous research on flange-to-flange connections and the use of shape memory alloy elements in concrete construction was consulted to develop two connection types for testing and comparison: commercially available shear/alignment connectors and shape memory alloy connector rods.
- Testing indicated that the shape memory alloy connectors are a promising connection detail that allows for connectors to be reused and provides improved ductility compared with the shear/alignment connectors.

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Double-tee beams include a flange and two webs, also known as stems, fabricated as one unit. This construction creates a structural member capable of withstanding high loads while having a long span. The typical flange width of double-tee beams is between 12 and 16 ft (3.6 and 4.9 m). The web depth is typically between 2 ft and 2 ft 8 in. (0.6 and 0.8 m), and with special forms can be up to 5 ft (1.5 m). The beams can generally span up to 80 ft (24 m), with some sections capable of spanning even greater lengths.[1] Double-tee beams are widely used by the precast concrete industry because they can be rapidly constructed in-plant, ensuring consistency in the material properties, curing procedures, and dimensions of the final product.

In the construction of large structures, flanges of adjacent double-tee beams are joined with mechanical connectors to resist horizontal shear forces from lateral loads (such as wind or earthquakes) and vertical shear from gravity loads and differential camber adjustments, and to withstand volume-change-induced forces.[1] The quality of the joints between the flanges of double tees is very important because these joints must incorporate adequate diaphragm connections to ensure overall structural stability as well as to provide displacement compatibility over a long service life.[2] Flange connectors include hairpin connectors, stud-welded connectors, deformed bar anchors, bent wings, mesh and angle connectors, structural tees, bent plate connectors, shear/alignment connectors, and proprietary flange connectors.[2,3] Connections are typically made using metal hardware cast into each flange. After erection, the hardware is welded using a loose jumper plate to weld the units together.

Deficiencies in design, construction, or maintenance of connections can result in premature distress of a joint. Deterioration of joints, longitudinal joints in particular, can affect the service life of a structure. Leakage through joint sealants is one of the effects that can sometimes occur due to improper quality control of sealant material installation.[2] It is difficult to properly install a backer rod for sealant installation where the mechanical brackets are located. Water can accumulate in concave joint locations, such as where the joint shape changes from flat to concave, leading to deterioration of sealants and causing corrosion and distress in connection brackets if not properly maintained.[4] Repair methods for damaged joints, such as replacing a connection, adding a support, or both, are available; however, these repair methods can be complicated and may not necessarily return the joint to its original strength.[4]

The goal of this study is to develop a durable and easily installed joint connection for double tees. Two different types of connections were selected and tested in vertical shear. The first is a shear/alignment connector. The second is a newly developed connection constructed using a superelastic shape memory alloy (SMA) curved bolt inserted into a duct that is cast into the precast concrete member. The superelastic SMA rod is proposed as a connector for two reasons: this material is noncorroding and highly durable, and it offers an efficient method to connect adjacent double tees by heating the SMA, thereby applying a post-tensioning force across the joint. In the event that degradation occurs, the SMA can be reheated to reapply the post-tensioning force.[5–7]

Literature review

Flange-to-flange connection performance

Testing has been conducted to evaluate the response of double-tee flange connectors under different loading conditions to emulate some of the actions expected in a double-tee floor system. Previous research has concluded that the bent wing connector, constructed using a bent strap of steel, the shear/alignment connector, and the proprietary flange connector provide the most dependable behavior in terms of strength and deformation capacity.[2,3]

An experimental program was carried out on the shear/alignment connector at the University of Wisconsin–Milwaukee to evaluate the performance of this connector under different loading conditions. The flange connectors used for this study were embedded in 4 ft × 4 ft × 4 in. (1.2 m × 1.2 m × 100 mm) concrete slabs and tested directly under horizontal and vertical shear and tension loading.[8] **Table 1** summarizes the results of testing A36 (250 MPa) steel and stainless-steel shear/alignment connectors under monotonic vertical shear.

After testing shear/alignment flange connectors for the precast concrete double-tee systems at the University of Wisconsin for many years, general guidelines for users of shear/alignment connectors were developed.[9–12] The intent of the guidelines is to enable shear/alignment connector users to benefit from its full tested capacities.

In-plane and out-of-plane shear tests were conducted on the proprietary flange connector at the ATLSS (Advanced Technology for Large Structural Systems) Research Center at Lehigh University.[3] The proprietary flange connector is intended for use as a precast concrete double-tee flange connector or for a connection between precast concrete wall elements. The test specimens were fabricated from two panels measuring 2 ft (0.6 m) wide, 4 ft (1.2 m) long, and 3.5 in. (89 mm) thick. The connector was tested under monotonic and cyclic in-plane shear and tension and out-of-plane shear. All tests were conducted under quasi-static displacement control at a rate less than 0.05 in./sec (1.3 mm/sec). **Table 2** summarizes the results of the out-of-plane shear tests.

A full-scale flexural test of precast concrete bridge deck panel transverse connections was conducted to determine the cracking and ultimate strengths of a newly proposed post-tensioned curved bolt connection. Each half of the specimen was 3 ft (0.9 m) long, 18 in. (0.46 m) wide, and 8.8 in. (0.22 m) deep.[13] Bolts were placed in two ducts spaced 3.5 in. (89 mm) apart (center to center) in the center of each specimen. Confinement reinforcement was placed around the ducts to prevent concrete cracking due to tensioning, and the bolts were tensioned to 300 psi (2070 kPa) of longitudinal stress over the entire transverse connection. The proposed curved bolt connection was shown to be a promising connection detail with approximately 0.5 times the theoretical capacity of a continuously reinforced panel. The researchers recommended that such connections be installed from the bottom of the bridge to eliminate blockouts and grouting on the deck surface.

Background of SMAs and their use in concrete structures

One of the first SMAs was the nickel titanium alloy that was developed in the early 1960s at the U.S. Naval Ordnance

Table 1. Summary of vertical shear test results on shear/alignment connector

Specimen number	Ultimate load, lb	
	A36 steel	Stainless steel
1	n/a	6000
2	5876	6000
3	5500	5989
4	n/a	5400

Source: Data from Shaikh and Feile (2002).

Note: n/a = not applicable. 1 lb = 4.448 N.

Table 2. Summary of vertical shear test results on proprietary flange connector

Specimen number	Carbon steel flange connector		Stainless steel flange connector	
	Ultimate load, lb	Corresponding displacement, in.	Ultimate load, lb	Corresponding displacement, in.
1	5010	0.46	4140	0.94
2	4320	0.21	5030	0.56
3	4380	0.46	n.d.	n.d.
4	4720	0.52	n.d.	n.d.

Source: Data from Ren and Naito (2010).

Note: n.d. = no data. 1 in. = 25.4 mm; 1 lb = 4.448 N.

Laboratory. It was discovered by accident when a sample was bent out of shape many times, subjected to heat, and then stretched back to its original shape. Currently, there are more than a dozen known SMAs; however, only those that can recover substantial amounts of strain, if not all, upon changing shape have potential structural applications. Examples of alloys with acceptable strain recovery include nickel titanium alloys and copper- or iron-based alloys.

Some materials can exist in more than one crystal structure. The two distinct crystal structures commonly found in SMAs are martensite and austenite. The martensitic phase occurs at lower temperatures and the austenitic phase exists at higher temperatures, with some overlap depending on the type of alloys used and the composition or ratio of the metals comprising the alloys. When an SMA is in its martensitic phase, it can be deformed, compressed, or stretched and will permanently retain the deformed or stretched shape until it is later heated to undergo a transformation into its austenitic phase.[14] For instance, when a prestrained SMA rod in its martensite form is subsequently heated, it experiences an austenitic transformation and reverts to its austenite phase. In this austenite phase, the SMA rod shrinks to its predeformed shape (that is, it becomes shorter).

Prestressing with SMA has been used for the confinement of concrete columns and concrete beams.[15–17] Prestressing provides increased confinement in columns and provides compressive stress to beams, thus minimizing tensile cracks and improving the structure's serviceability and durability.[15] While conventional prestressing requires an anchoring system and hydraulic devices to apply the prestressing force, prestressing with SMA can be achieved by heating the SMA.

Several experimental investigations on concrete structures have been conducted using SMAs. Joints in a tunnel lining were temporarily strengthened by SMA (Ti-50.0 wt% Ni) bolts.[18] The goal of the proposed method was to create favorable conditions for the permanent strengthening that followed. Four steel bolts with a diameter of 1.2 in. (30 mm) and an initial length of 1.6 ft (0.49 m) were used in this loading test. Two neighboring segments were tightly assembled, then a horizontal load was applied and maintained constant. Next, vertical loads were gradually applied to the specimen until the joint opening increment reached the target value. Two SMA bolts were placed in the specimen and heated to 320°F (160°C). The results showed that this strengthening method could efficiently reduce joint opening, joint deflection, and concrete strain in the compression zone.

A self-repairing concrete beam was investigated using the superelastic effect of an SMA.[19] The SMA wire used in the study was Ni-50.8 wt% Ti with an ultimate tensile strength of about 133,435 psi (920 MPa) and an ultimate strain of about 19%. The specimens used in this experiment were reinforced concrete beams with 4 in. (100 mm) sides in the cross section and 15.7 in. (0.4 m) length. The main reinforcement was SMA wires (20 in. [0.5 m] long and 0.08 in. [2 mm] in diameter in the tensile area). A concentrated load was applied to the midspan of the beam with a static deformation rate. Experimental results showed that the superelastic SMA wires added a self-restoration capacity to the beams. The deflection of the beams reversed, and the crack closed almost completely after unloading.

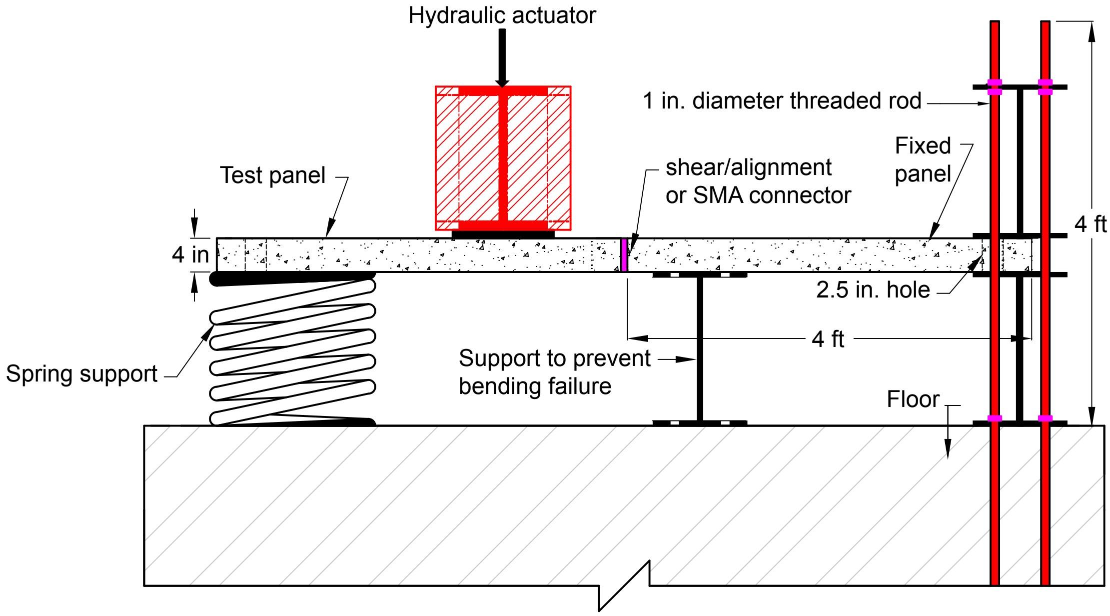
SMA used as a prestressing element in structures such as bridges and parking structures is often subjected to external cyclic loading due to traffic, temperature changes, wind, and the like. Therefore, SMA fatigue behavior should be investigated. The fatigue behavior of an iron-based SMA specimen used for prestressed strengthening in civil structures was examined by applying 2 million cycles.[20] After 2 million cycles, no material fracture was observed. However, the recovery stress decreased by nearly 10% and 20% for the applied strain ranges of 0.035% and 0.07%, respectively. Therefore, this loss in the recovery stress should be considered in the structural design.

Experimental program

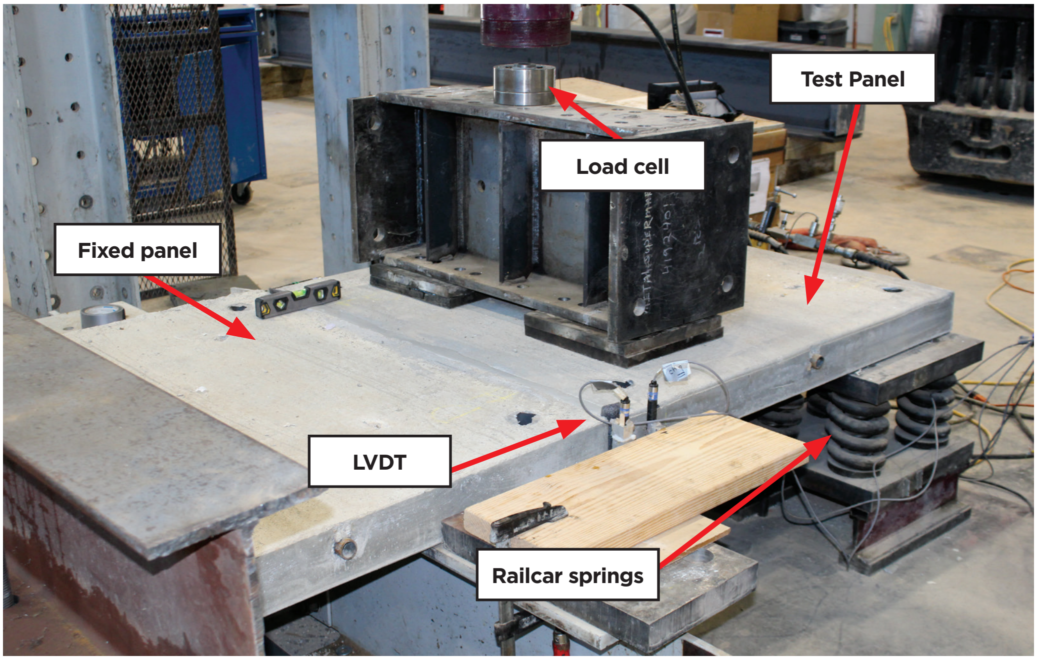
For comparison purposes, two different types of connections were investigated. The first was the shear/alignment connector, which is commonly used in the industry. The second was a newly proposed SMA curved bolt connection. The SMA rod (Ni-50.9 wt% Ti) had a diameter of 0.5 in. (12 mm) and length of 39.8 in. (1 m).

The test specimen was fabricated from two 4 × 4 ft (1.2 × 1.2 m), 4 in. (100 mm) thick concrete panels to mimic a pretopped double-tee beam. The two panels were named fixed and test panels based on their locations in the test setup and reinforcement details (**Fig. 1**). **Figures 2** to **5** show reinforcement details and photographs of both the shear/alignment connector and SMA specimens. The fixed and test panels were connected to form a 4 × 8 ft (1.2 × 2.4 m) subassembly.

Temperature and shrinkage reinforcement in accordance with the American Concrete Institute's *Building Code Requirements for Structural Concrete (ACI 318-14) and Commentary (ACI 318R-14)*[21] was used in each concrete panel in the form of welded-wire reinforcement (W6 × W6 [152 × 152 mm]). In addition, no. 3 and 4 (10M and 13M) reinforcing bars were used to strengthen the boundary of the test subassembly as flexural and shear reinforcement, respectively. The steel rein-

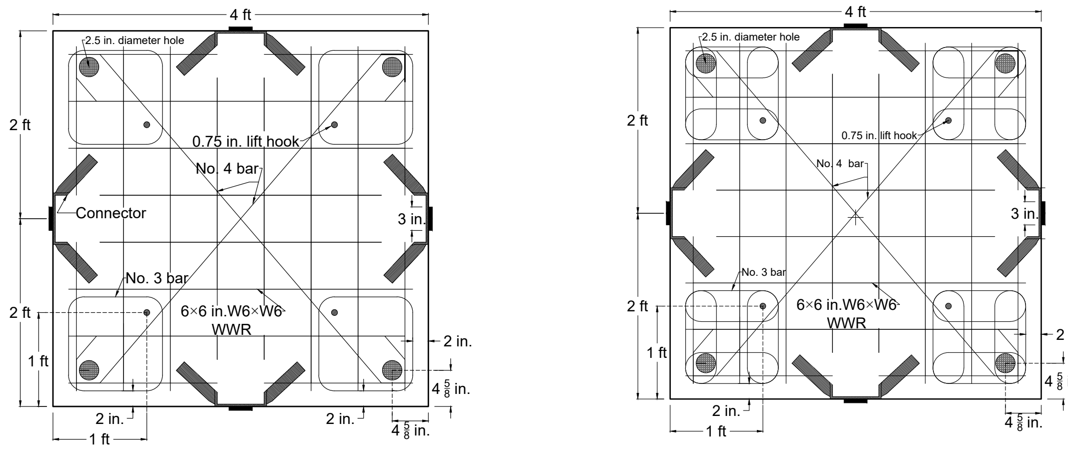


Schematic



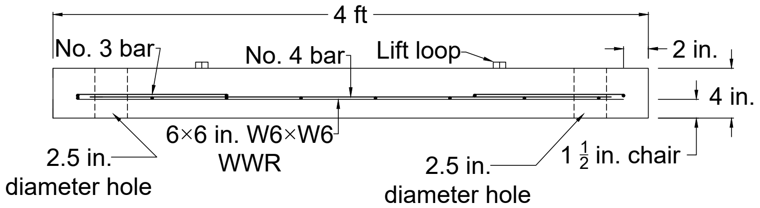
Actual test setup

Figure 1. Test setup. Note: LVDT = linear variable displacement transducer; SMA = shape memory alloy. 1 in. = 25.4 mm; 1 ft = 0.305 m.

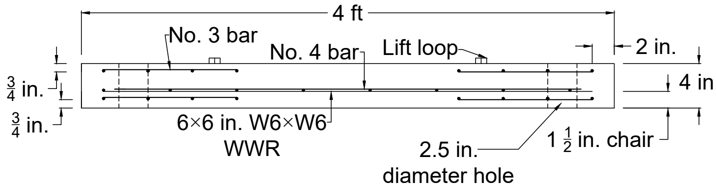


Test panel plan view

Fixed panel plan view



Test panel elevation view



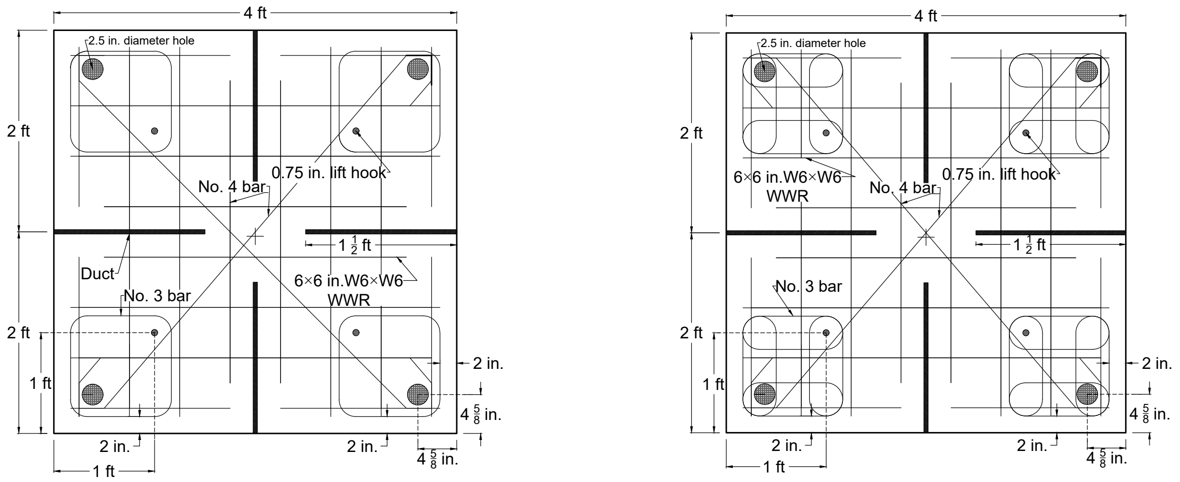
Fixed panel elevation view

Figure 2. Slab reinforcement details of the shear/alignment connector specimen (behind the connector). Note: WWR = welded-wire reinforcement. No. 3 = 10M; no. 4 = 13M; 1 in. = 25.4 mm; 1 ft = 0.305 m; W6 = 152 mm.

forcement in the test panel was designed to replicate common practice for double-tee flanges in the precast concrete industry (Fig. 2 and 3). In the fixed panel, additional steel reinforcement was added to avoid flexural and shear cracks (Fig. 2 and 3) because each panel was designed to be tested four times. The positioning of the shear/alignment connector (**Fig. 5**) was based on the connector's user guidelines.[12] For the SMA connectors, a duct made of 1 and 2 in. (25 and 50 mm) diameter steel pipes welded together was cast into the panel at the center of each edge (Fig. 4 and 5). The panels were cast with concrete with a 28-day design strength of 5000 psi (34 MPa) and maximum aggregate size of ¾ in. (19 mm) to replicate typical precast concrete construction. The specimens were cured with wet burlap for 28 days.

Preparation of SMA rods

A tensile prestrain of 8% at ambient temperature was applied to all SMA rods (**Fig. 6**). Figure 6 shows the prestraining behavior of the SMA rods. One sample was chosen for stress recovery measurement. The SMA rod was placed inside a heating chamber (Fig. 6). A small stress was applied at ambient temperature to avoid a gap between the sample and the clamps of the machine. After that, the sample was heated to 284°F (140°C) (that is, 44% of the target temperature, 608°F [320°C]) and then cooled back to ambient temperature while keeping the strain constant. This step was performed to obtain the recovery stress–temperature curve for the SMA rods subjected to prestrain (Fig. 6). The temperature inside the chamber was



Test panel plan view

Fixed panel plan view

Figure 3. Slab reinforcement details of shape memory alloy specimen. Note: WWR = welded-wire reinforcement. No. 3 = 10M; no. 4 = 13M; 1 in. = 25.4 mm; 1 ft = 0.305 m; W6 = 152 mm.

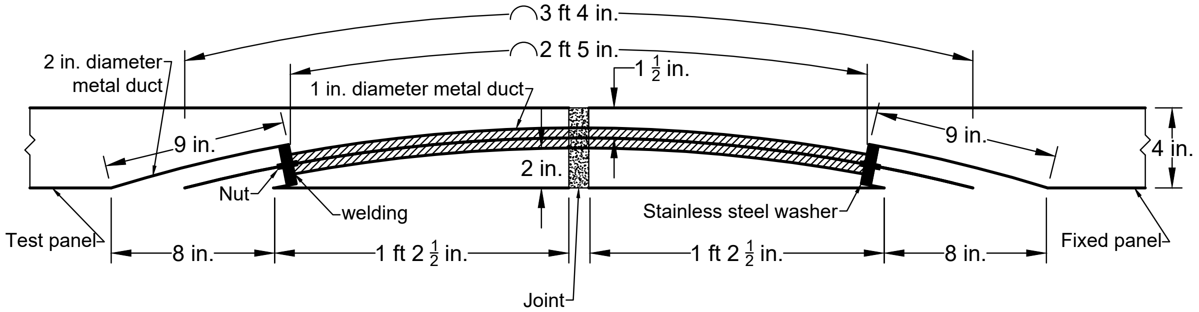
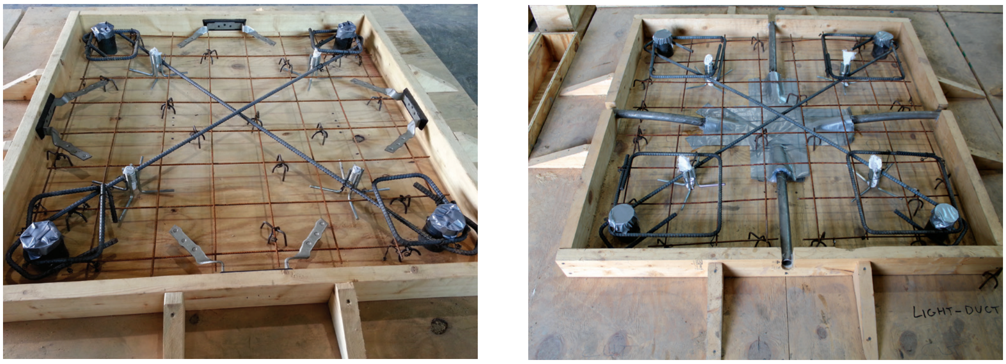


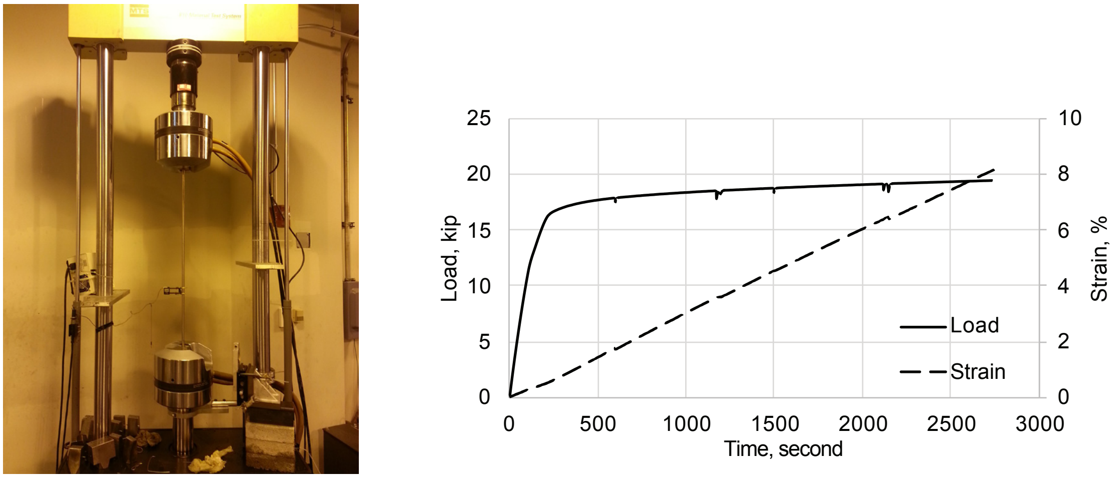
Figure 4. Shape memory alloy connector details. Reinforcement details are similar to the shear/alignment connector panel details shown in Fig. 2. Note: 1 in. = 25.4 mm; 1 ft = 0.305 m.



Shear/alignment connector test panel

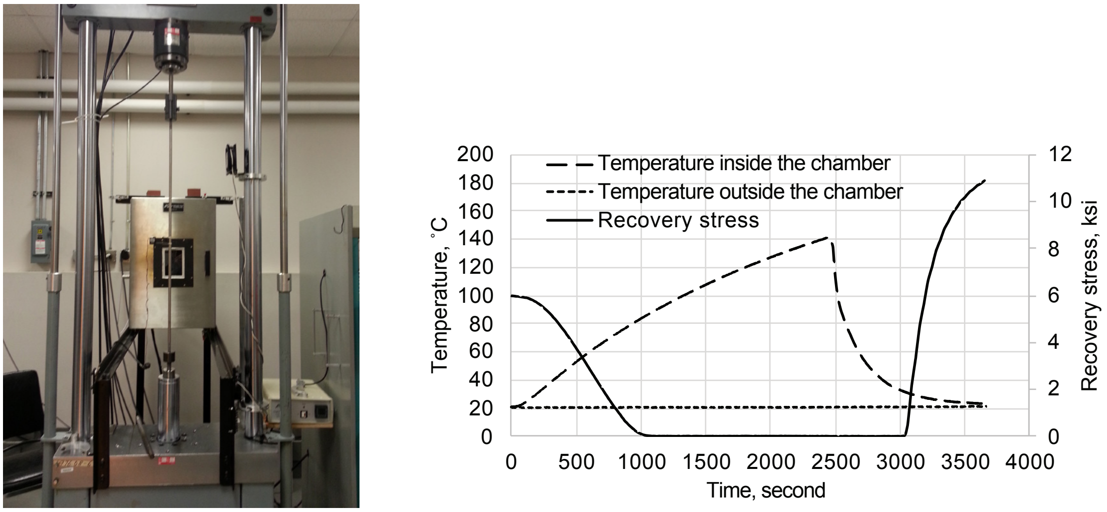
Shape memory alloy connector test panel

Figure 5. Panel reinforcement details.



Prestraining

Prestraining response



Heating and cooling

Measured recovery stress-temperature curve

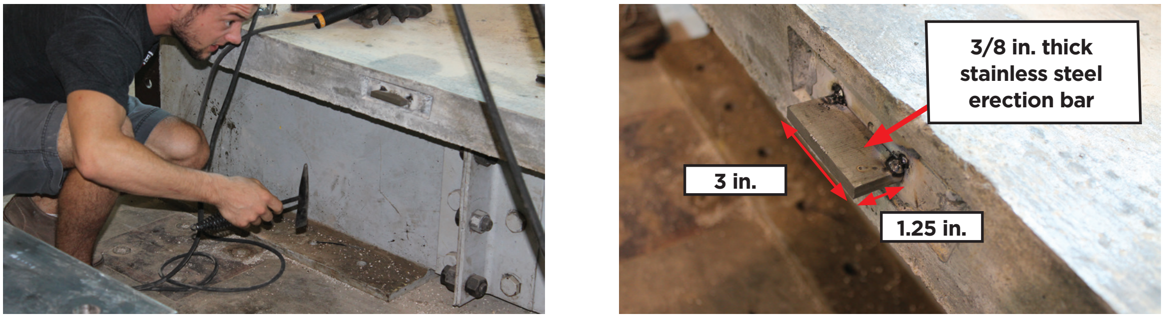
Figure 6. Preparation of shape memory alloy rods. Note: 1 kip = 4.448 kN; 1 ksi = 6.89 MPa; °C = (°F – 32)/1.8.

recorded by a thermocouple attached to the SMA rod. The higher the applied temperature, the more recovery stress can be realized. Therefore, an SMA rod is expected to have more recovery stress when it is heated to 608°F. The maximum target temperature was selected as the maximum value, based on the manufacturer's advice, to ensure that the physical properties of the SMA rods were maintained.

Joint preparation

Shear/alignment connector Based on the user guidelines for the shear/alignment connector,[12] stainless-steel flat ⅜ in. (9.5 mm) thick and 3 in. (75 mm) long erection bars were used. The A304 stainless-steel flat erection bar was connected to the shear/alignment connector by a fillet weld using an E308 electrode. The flat erection bars were placed such that their top surfaces were 0.25 in. (6.3 mm) below the top edge of the shear/alignment connector but no more than 0.75 in. (19 mm) below the top of the shear/alignment connector. **Figure 7** shows the welding process of the flat erection bar.

After welding, the sealant material was added and cured. Then the specimen was ready for testing. Two types of sealant materials were used in different shear/alignment connector specimens: a self-leveling polyurethane elastomeric sealant that is commonly used in double-tee joints and a nonshrink cementitious grout. **Figure 8** shows the application of sealant materials in the shear/alignment connector specimens.



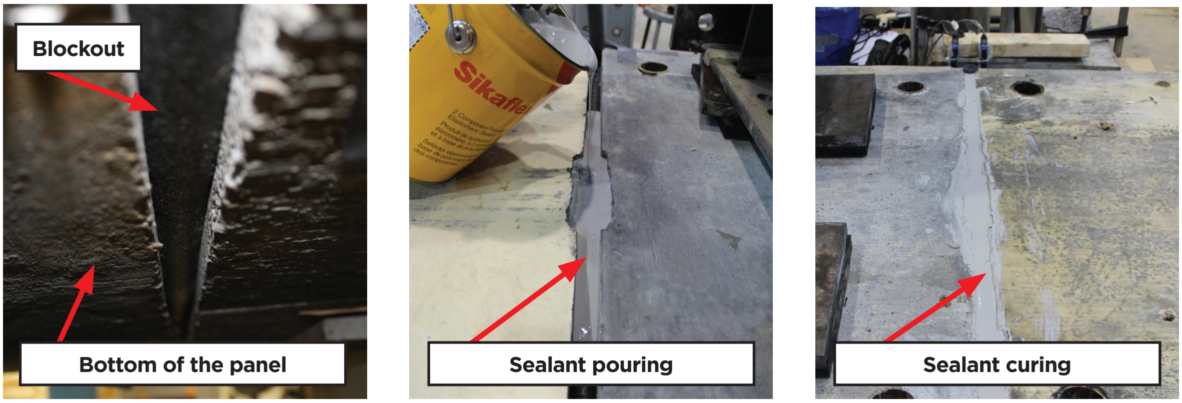
Welding the erection bar to the fixed panel

Erection bar details

Welding the erection bar to the test panel

Erection bar after welding

Figure 7. Welding process for the shear/alignment connector. Note: 1 in. = 25.4 mm.



Applying self-leveling polyurethane elastomeric sealant

Applying nonshrink cementitious grout

Figure 8. Applying sealant materials for the shear/alignment connector specimens.

SMA connector After prestraining the SMA rods, the following steps were taken to prepare the SMA connector for testing (**Fig. 9** and **10**):

1. Both ends of the SMA rod were threaded, and the rod was bent to a radius of 6.5 ft (2.0 m).

2. A heating cord was wrapped around the rod.

3. The rod was inserted into the right slab; then the left slab was adjusted to align the SMA rod with the embedded duct.

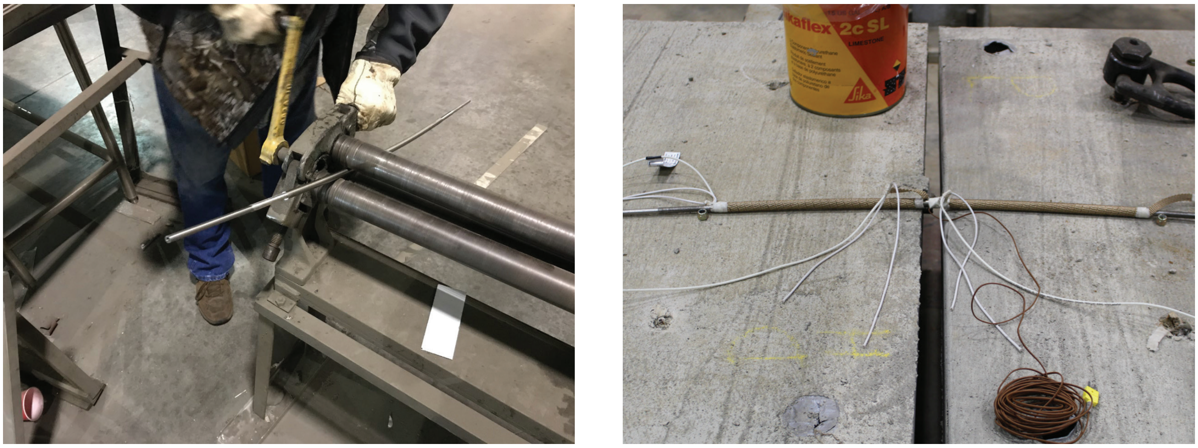
4. The nuts at both ends of the rod were tightened until the joint width reached the design value.

5. The sealant material was applied and cured. As with the shear/alignment connector specimens, two types of sealant materials were used in different SMA connector specimens: a self-leveling polyurethane elastomeric sealant and a nonshrink cementitious grout.

Experimental setup and testing

The experimental subassembly approximated the boundary conditions of an embedded connection typically used between flanges of two adjacent precast concrete double tees. The connection specimen consisted of a pair of 4 × 4 ft (1.2 × 1.2 m) concrete slabs with a thickness of 4 in. (100 mm). Figure 1 shows a schematic of the experimental subassembly explaining the boundary conditions. The fixed panel had one fixed end and a simple support beneath the other end. The load was applied to the test panel to maximize the shear force and minimize the moment in the joint. The test panel was supported by double-coil railcar springs with an average spring constant of approximately 13,400 lb/in. (2347 kN/m).

Each SMA connector test was initiated by heating the SMA rod to about 608°F (320°C). During this time, the nuts at both ends became loose due to elongation of the heated SMA rod. The nuts were then retightened when the maximum temperature was reached to achieve higher recovery stress. When the SMA rod cooled down, a prestressing force was applied across the joint. A

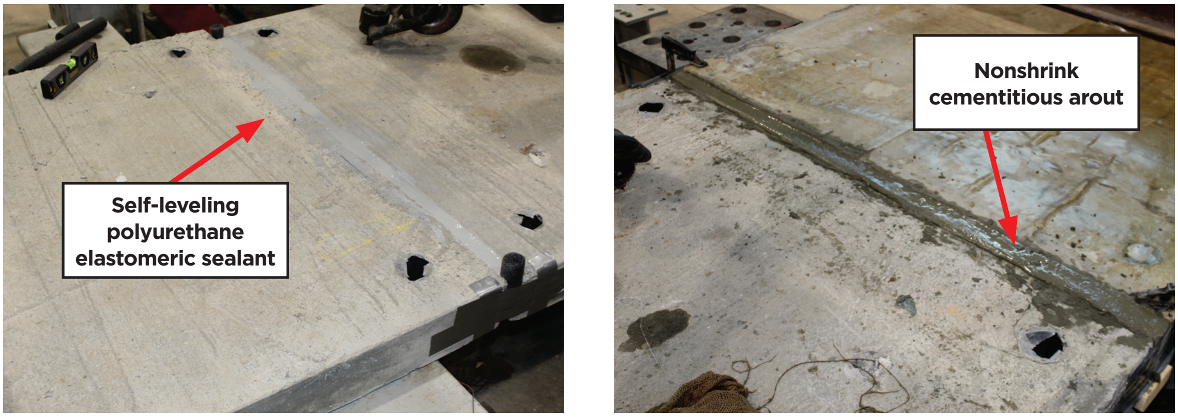

Shape memory alloy rod bending

Wrapping the heating cord


Inserting shape memory alloy rod in both panels

Tightening the nut from the bottom

Figure 9. Shape memory alloy rod installation.



Self-leveling polyurethane elastomeric sealant

Nonshrink cementitious grout

Figure 10. Applying joint materials for shape memory alloy connector specimen.

thermocouple was used to measure the surface temperature of the SMA sample during the heating and cooling process. The load was applied monotonically with a hydraulic ram to determine the vertical shear resistance of the connections. During each test, linear variable displacement transducers positioned on each side of the joint were used to monitor vertical displacement and joint openings in the specimen (Fig. 1). **Table 3** summarizes the test plan.

Results and discussion

This section presents the performance results of the shear/alignment and SMA connections subjected to monotonic out-of-plane shear. For both connections, the behavior of the test specimen was characterized by cracking and spalling in the area where the shear/alignment connector legs or SMA rods were embedded. **Figures 11** and **12** show the failure modes of the shear/alignment and SMA connections, respectively. For the SMA connection, concrete spalling from the bottom surface of the fixed panel and the top surface of the test panel was observed (Fig. 12). Only concrete spalling from the top surface of the test panel was observed for the shear/alignment connector specimen (Fig. 11). The failure mode of the shear/alignment connection was a result of concrete breakout above the connector. This may be attributed to the short embedded length of the shear/alignment connector legs compared with the SMA rod and duct. In other words, for the shear/alignment connector specimen, the connector legs were observed pulling out from the concrete panel, whereas for the SMA rod and duct, pressure failure toward the bottom panel surface during loading was observed.

The load-displacement behaviors of the shear/alignment connector and SMA specimens with different joint materials were investigated. For the SMA connector, lower stiffness was observed when using the polyurethane elastomeric sealant compared with the nonshrink cementitious grout (**Fig. 13**). The average stiffnesses of the SMA specimens with the nonshrink cementitious grout and with the polyurethane elastomeric sealant were 116,681 and 17,760 lb/in. (20,434 and 3110 kN/m), respectively. For the shear/alignment con-

Table 3. Summary of testing plan

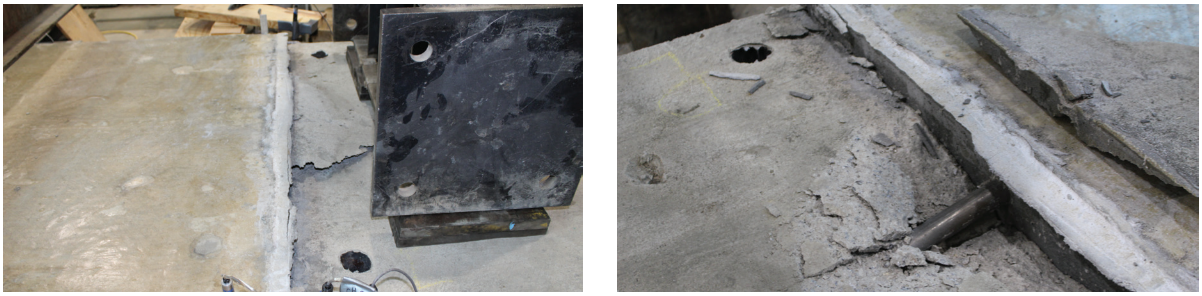
Number of specimens	Length, ft	Width, ft	Thickness, in.	Mechanical connection type	Joint material	Number of tests
1	4	4	4	Shear/alignment	Polyurethane elastomeric sealant	2
1				Shear/alignment	Nonshrink cementitious grout	1
1				Shape memory alloy, 0.5 in. diameter	Polyurethane elastomeric sealant	1
1				Shape memory alloy, 0.5 in. diameter	Nonshrink cementitious grout	3

Note: 1 in. = 25.4 mm; 1 ft = 0.305 m.

Concrete spalling from the top surface of the test panel

Shear/alignment connector embedded in panels at failure

Figure 11. Failure mode of shear/alignment connector with self-leveling polyurethane elastomeric sealant. Note: 1 in. = 25.4 mm.



Concrete spalling from the top surface of the test panel

Concrete spalling from the bottom surface of the fixed panel

Figure 12. Failure mode of shape memory alloy connector with grout.

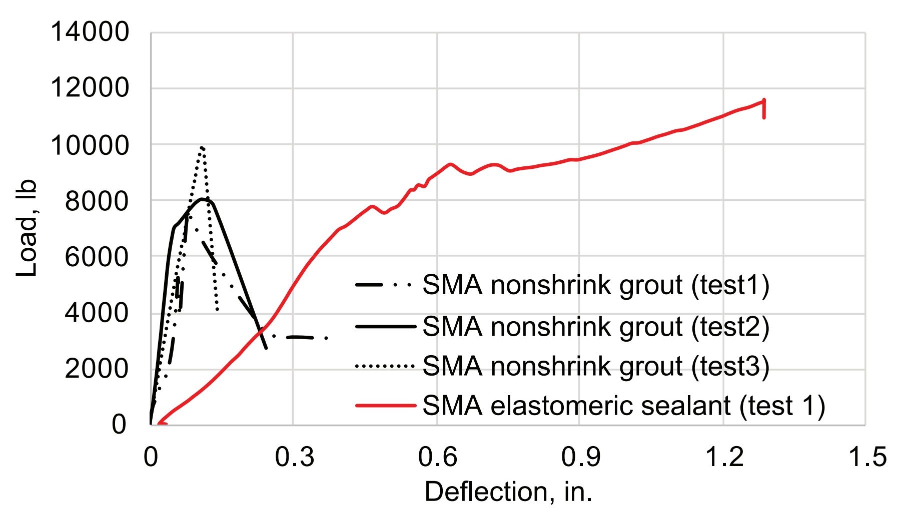


Figure 13. Comparison of load and displacement behavior of the shape memory alloy (SMA) connector with nonshrink cementitious grout and self-leveling polyurethane elastomeric sealant. Note: 1 in. = 25.4 mm; 1 lb = 4.448 N.

nector specimens with the polyurethane elastomeric sealant, the average stiffness was 31,300 lb/in. (5481 kN/m) (**Fig. 14**). Figure 14 shows that several load reductions occurred before the ultimate capacity was reached when testing the SMA specimen with the polyurethane elastomeric sealant, which indicates signs of failure before the final collapse; however, sudden failure was detected when testing the shear/alignment connector specimen with the polyurethane elastomeric sealant, which indicates lower ductility in the shear/alignment connector specimens than the SMA specimens (Fig. 14). More testing is recommended to confirm this behavior.

Table 4 summarizes the maximum loads and corresponding displacements of both connection types. One important difference between the two connector types is that the SMA connector can be reused by reapplying heating and cooling, which was confirmed by conducting more than two tests using the same SMA rod.

Figure 15 shows the SMA rod condition after several tests. Moreover, the SMA connector exhibited a consistent response between the tests, while the shear/alignment connector response was more variable, potentially due to the welding process.

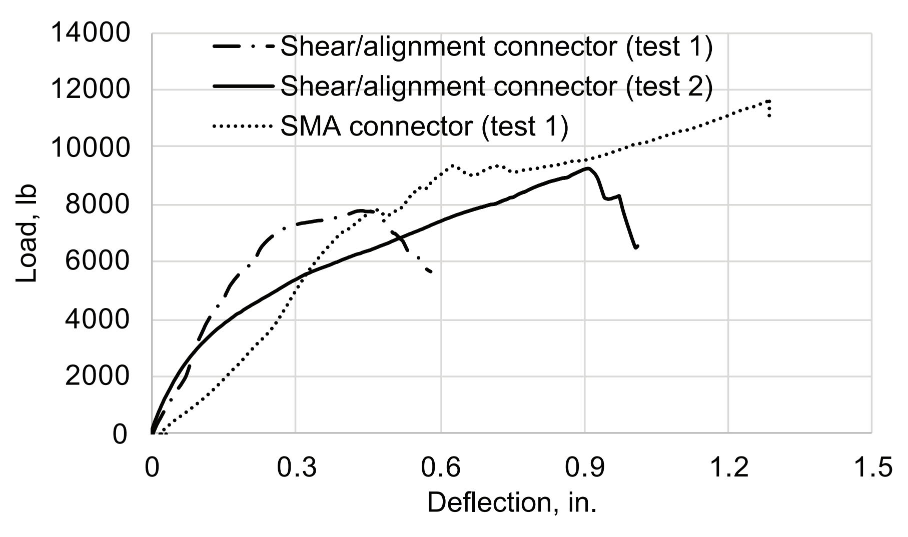


Figure 14. Comparison of load and displacement behavior of the shape memory alloy (SMA) and shear/alignment connectors using self-leveling polyurethane elastomeric sealant. Note: 1 in. = 25.4 mm; 1 lb = 4.448 N.

Table 4. Summary of vertical shear test results on shear/alignment and shape memory alloy connectors

Number of specimens	Mechanical connection	Joint material	Number of tests	Ultimate load, lb	Corresponding displacement, in.
1	Shear/alignment	Polyurethane elastomeric sealant	2	7738	0.43
				9250	0.9
1	Shear/alignment	Nonshrink cementitious grout	1	8825	0.68
1	Shape memory alloy	Polyurethane elastomeric sealant	1	12,976	1.28
1	Shape memory alloy	Nonshrink cementitious grout	3	7613	0.07
				8075	0.11
				9963	0.11

Note: 1 in. = 25.4 mm; 1 lb = 4.448 N.

Figure 15. Shape memory alloy rod condition after reuse.

Conclusion

This study examined the out-of-plane shear performance of the flange-to-flange connection between precast concrete double-tee members. Two connector types were investigated: a commonly used shear/alignment connector and the newly proposed SMA rod connector. The connectors were tested under monotonic out-of-plane shear, and the resulting capacities and associated damage were summarized. The conclusions are as follows:

- Higher stiffness was observed for SMA connectors with the nonshrink cementitious grout compared with the polyurethane elastomeric sealant.
- Higher ductility was observed for SMA connectors compared with shear/alignment connectors both with the polyurethane elastomeric sealant. More tests should be conducted to confirm this behavior.
- Different failure modes were observed for different connections. For the SMA connection, concrete spalling was observed from the bottom surface of the fixed panel and the top surface of the test panel. The failure mode of the shear/alignment connection was concrete breakout above the connector due to the connector legs pulling from the concrete.
- The SMA rod can be reused by reheating the SMA element, which is not the case for the shear/alignment connector or other similar connectors.

Based on the observations from testing the newly proposed flange-to-flange connector between precast concrete double-tee members, recommendations for future research and development are as follows:

- More tests should be conducted on SMA rod connectors using different joint materials to confirm the behavior observed in this study.
- The shear/alignment connector and SMA rod connector joint behaviors should be investigated under fatigue loading.
- Different heating methods should be studied to simplify the process, such as reusing the same heater without taking out the rod or using a new heater.

- High-temperature strain gauges should be attached to the rod to measure the actual recovery strain.

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Abstract

This study investigated the out-of-plane shear performance of a newly developed shape memory alloy (SMA) connector and a commonly used shear/alignment connector. The innovation lies in developing a durable and easily installed and maintained flange-to-flange connector between precast concrete double-tee members. The proposed connector consists of a superelastic SMA curved bolt inserted into a duct that is then cast into the precast concrete member. Two types of sealant materials were used: polyurethane elastomeric sealant and nonshrink cementitious grout. The shear/alignment and SMA connectors were tested under monotonic vertical shear. The tests were conducted on 4 ft × 4 ft × 4 in. (1.2 m × 1.2 m × 100 mm) slab specimens. The resulting capacities and associated damage were summarized. Higher stiffness and lower ductility were observed for the SMA connector with nonshrink grout compared with the shear/alignment connector with polyurethane elastomeric sealant. The average stiffnesses of the SMA and shear/alignment connector specimens were 116,681 lb/in. (20,434 kN/m) and 31,300 lb/in. (5481 kN/m), respectively. The ductility of the SMA connector was improved when using polyurethane elastomeric sealant; however, more tests should be done to confirm this behavior. The SMA rod was reused in several tests through reheating of the SMA element. The shear/alignment connector cannot be reused.

Keywords

Double tee, flange connection, shape memory alloy, shear/alignment connector.

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