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Shear Load Transfer by Double Dowel Connectors

L X Zheng, National University of Singapore, Singapore
C J Burgoyne, University of Cambridge, United Kingdom

ABSTRACT

In concrete construction, shear force often needs to be transferred across a movement joint. Conventional methods of transferring shear at a movement joint rely on the provision of dowel bars, concrete shear keys, or dual supports on both sides of the joint. The conventional methods have disadvantages, such as complicated construction procedures, increased site work and use of more materials. To overcome these difficulties, a double dowel shear connector using stainless steel has been developed to carry shear force across movement joints.

The shear connector consists of two stainless steel components; a sleeve component and a double dowel component. Its features and method of installation are described. Tests were carried out to investigate the load carrying capacity and failure mechanism of the connector.

The test specimens consisted to two concrete slab elements with two double shear connectors in the slab-slab joint. The joint width was taken as a parameter influencing the load capacity of the connector. The specimens were subjected to shear load. Failure of the specimens started with cracking of unreinforced concrete in the cover zone. As the applied load was further increased, the cracks developed and the damaged concrete tended to separate from the main body of the specimen. At failure, the connector deformed plastically and shifted from its original embedded position in the concrete.

Test results show that, when properly used, the connector can resist shear load satisfactorily. A plastic model is proposed to describe the behaviour of the connector at ultimate load and the estimated ultimate loads using the model agree well with the test results. Unreinforced concrete around the connector is sensitive to the splitting effect of shear force, so attention should be given to reinforcement detailing.

1. Introduction

In concrete construction, shear force often has to be transferred across a movement joint, as in suspended floor slab construction or in ground floor slab construction where differential displacement at the joint needs to be controlled. Conventional methods for transferring shear across a movement joint rely on the provision of dowel bars, concrete shear keys, or dual supports on both sides of the movement joint. These methods have disadvantages, such as complicated construction procedures, increased work on site and use of more materials. To overcome these difficulties, a double dowel shear connector system using stainless steel was developed by a Swiss company to transfer shear force across a movement joint[1].

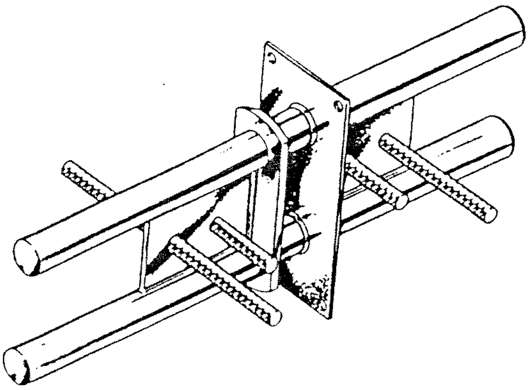


Figure 1 Shear Connector, exploded view

The shear connector consists of two stainless steel components; the sleeve and the dowel, as shown in Figure 1. The sleeve has two tubes which are joined by both a steel plate that is embedded in the concrete, and a surface plate. Short pieces of reinforcing bar protrude from the reinforcing plate. The dowel component is similar, but has two dowels in place of the sleeves.

To make a joint, the sleeve portion is fixed to the inside of the formwork on the first piece of concrete to be cast. When the formwork is removed, the sleeve holes are exposed and the dowel portion can be inserted into the sleeve. A joint filler board material, which will allow movement and may be a low density polystyrene or similar product, is used to ensure that the correct gap is left between the two components.

A number of possible applications have been envisaged by the manufacturer. They can be used in slab-slab connections where differential settlement needs to be controlled; in slab to beam connections and in slab-wall connections. Figure 2 illustrates some of these applications.

Tests of the shear connectors were carried out for the British Licensee of the system, Ancon Clark Ltd[2]. (The product was originally developed by a Swiss company, Pflueger & Partner AG[1]). The aim of the study was to find the load capacity and to investigate the failure mechanism of the connector system[3].

2. Description of the Connectors

Two types of the shear connectors were tested. These were Staifix DSD50 and DSD75 (as named by Ancon Clark Ltd.), which differ in size and load carrying capacity. Figure 3 shows the connector and the dimensions are listed in Table 1. The material used to make the connectors is an austenitic grade of stainless steel. It shows early plastic deformation in test but continues to sustain increasing load with increasing strain. There is no well-defined yield point when subjected to tensile load. Instead of a yield stress, the 0.2% proof stress of 800 N/mm^2 is used in design. The ultimate tensile strength is about 850 N/mm^2.

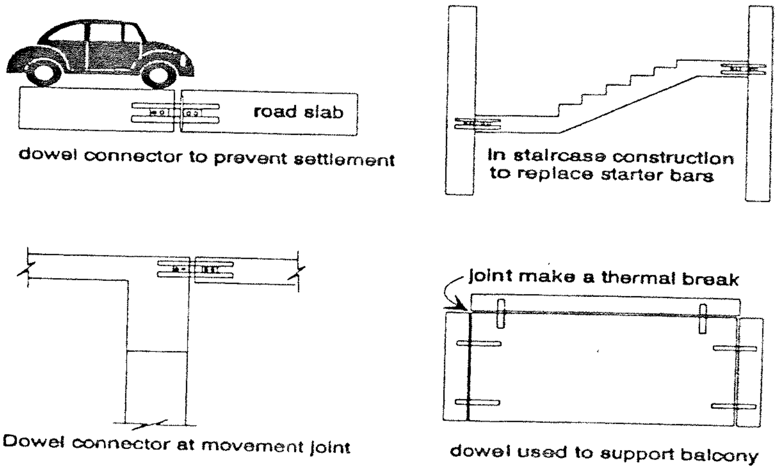


Figure 2 Application of the dowel connector

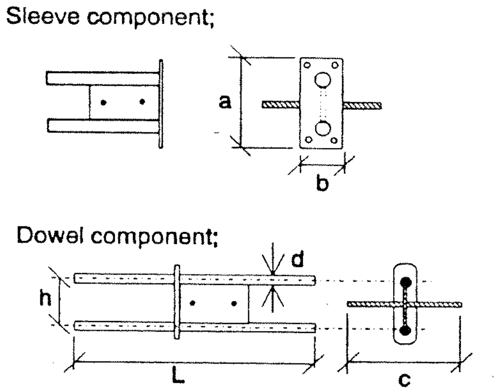


Figure 3 double dowel connector

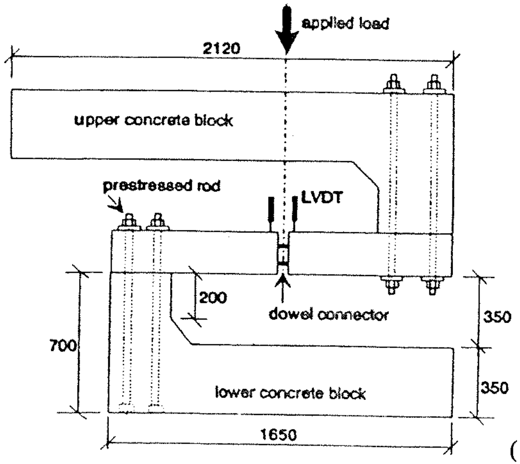
Table 1 Dimensions of connector (mm)

Connector Type	Staifix DSD50	Staifix DSD75
Dowel Dia.(d)	18	22
Length (L)	280	340
a	100	150
b	60	70
c	160	180
h	50	75

3. Experimental Program

Loading Arrangement

To apply a pure shear load to a joint formed between slab elements, two "L" shaped concrete blocks were connected to the ends of a jointed slab specimen to form a "squashed-S" shape, as shown in Figure 4, with the joint immediately below in the middle of the "S". The size of the top block was arranged in such a way that the dead weight of the top half passed through the joint as a shear force.



(all units in mm)

Figure 4 "S"-shaped assembly for application of shear load

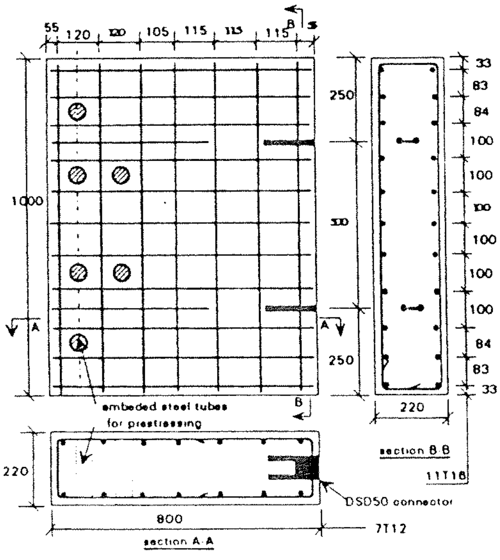
The load was applied by a 100 Tonne hydraulic jack reacting against a steel frame which spanned the joint transversely and was bolted to the laboratory floor. Prestressing was used to connect the concrete blocks to the slab specimen.

Details of Specimens

Two shear connectors were used in each specimen which consisted of two slab elements. The dimensions of the slab elements used for the two different types of connectors, i.e. DSD50 and DSD75, are listed in Table 2. The thickness of the slab was typical for the size of the connector used and the width was chosen to accommodate two connectors, while aiming to prevent the failure mode of the two connectors from interacting. The length of the slab element was chosen to ensure that no part of the support or loading mechanism came within two slab thickness of the joint.

Table 2 Dimensions of slab element (mm)

Staifix Connector	thickness	width	length
DSD50	220	1000	800
DSD75	260	1000	800



(all units in mm)

Figure 5 Details of DSD50 specimens

Reinforcement for the specimens was designed to BS8100 using high yield deformed bars. Reinforcement details for the DSD50 specimens are shown in Figure 5; those for the DSD75 specimens were similar.

Ready mixed concrete with a nominal characteristic strength of 25 N/mm^2 was used, although the average cube strength of the concrete at 28 day was about 36 N/mm^2. The slab units containing the sleeve components were cast first. Polystyrene boards of the specified joint width were used as joint filler. Four days after the casting of the sleeve slabs, the dowel slabs were cast.

Five specimens were made for the DSD50 connector and another five for the DSD75 connector. The joint widths varied from 10 mm to 50 mm with an increment of 10 mm. The five DSD50 specimens are referred to as DSDA10 to DSDA50, with the figure indicating the joint width. The five DSD75 specimens were referred to as DSDB10 to DSDB50.

Instrumentation

The relative displacements of the two slabs under loading were recorded using linear variable displacement transducers (LVDTs). The positions of the LVDTs are indicated in Figure 4. A computer controlled data logger took readings of displacement and load.

Test Procedure

A jointed specimen was lifted with a purpose-made lifting frame to prevent accidentally loading the joint during handling. One end of the specimen was bolted down to the lower concrete block and the other end rested on a temporary support (refer to Figure 4). The prestressing forces in the bolts were designed to carry the moment caused by the applied load without losing compression across the contact surface. After the specimen was set up in the "S"-shaped form, the steel loading frame was lifted over the top of the assembled concrete rig and bolted to the laboratory floor.

When the applied load from the hydraulic jack was zero, the temporary support was removed, so the dead weight of the top concrete block acted on the joint. The load in the jack was increased gradually. The true load acting on the connector was the jack load plus the dead weight of the upper concrete block.

Mode of Failure

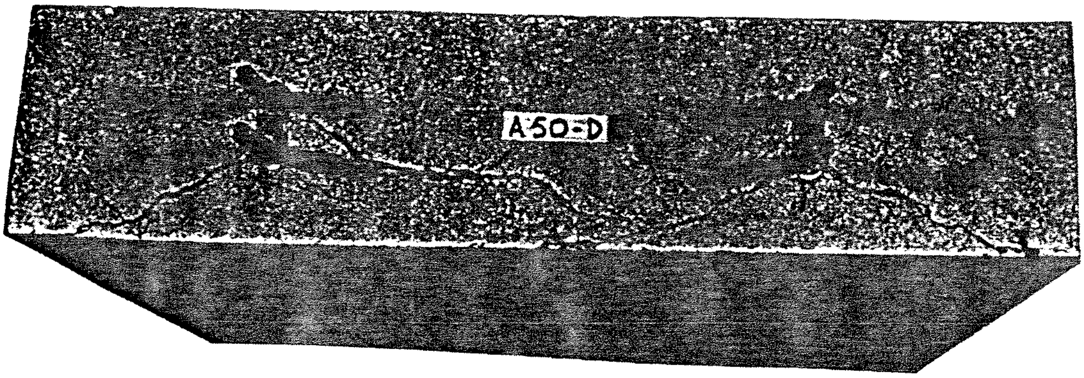
When the applied load reached a high level, the first sign of failure was the sound of concrete cracking. Concrete cracks running nearly parallel to the width of the slab could be seen. When the load started to drop the test was stopped. Figure 6 shows specimen DSDA50 after testing. When the damaged concrete was removed from the slab component, it showed that the unreinforced concrete, i.e. the concrete in the cover region, suffered serious damage, while concrete inside the reinforcement cage was still in good condition. Failure modes of the other specimens were similar to that of specimen DSDA50.

4. Test Results

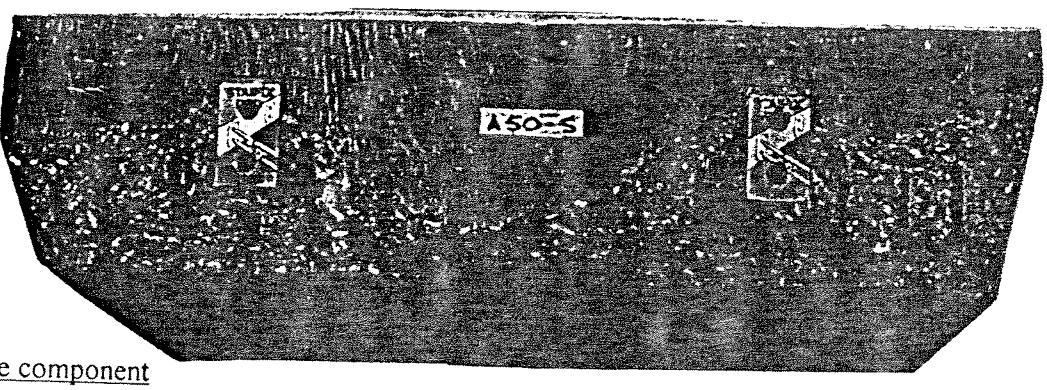
Results of DSDA (or Staifix DSD50) Connector Tests

Specimens DSDA10, DSDA30, DSDA40 and DSDA50 were tested using the test setup shown in Figure 4. Relative displacements of the two slab components at the joint were recorded at various loading steps and these values are given in Table 3.

The load carrying capacity of the specimens decreased with an increase in the joint width, as shown in Figure 7.



Dowel component



Sleeve component

Figure 6 specimen DSDA50 after test (with Staifix DSD50 connectors)

Table 3 Test results of specimens using Staifix DSD50 (DSDA) connectors

Vertical displacement (in mm)

Load (kN)	DSDA10	DSDA20*	DSDA30	DSDA40	DSDA50
0	0.00	0.00	0.00	0.00	0.00
26	0.02	0.18	0.07	1.22	0.32
36	0.06	0.30	0.20	1.37	0.37
46	0.16	0.43	0.40	1.63	0.56
56	0.26	0.62	0.63	1.92	0.94
66	0.37	0.84	0.95	2.31	1.43
76	0.52	1.15	1.34	3.06	2.12
76.5					4.96
86	0.70	1.50	1.84	4.26	
91.8				6.13	
96	0.95	2.07	3.20		
102.3			6.92		
106	1.23	1.70			
116	1.76	3.86			
126	4.01	8.38			
127.8		10.72			
132.2	10.71				

* DSDA20 tested using modified setup (Figure 8)

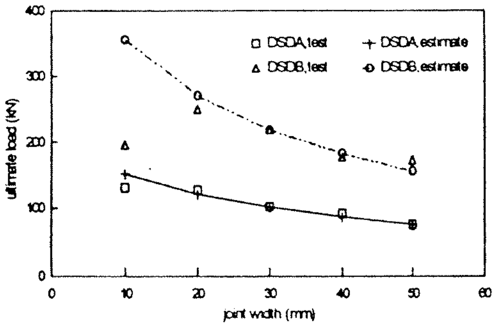
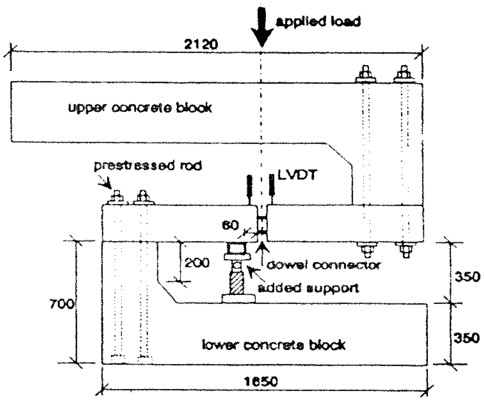


Figure 7 Relationship between load capacity and joint width, DSDA & DSDB series

The test setup for specimen DSDA20 was slightly different from that of the others. A support beam was provided under the slab component on the left hand side of the joint, as shown in Figure 8, in order to study the effect of a support close to the joint. In a previous study of the connector system by the Swiss company that developed it^2, similar specimens were tested using a setup in which a support beam was located at each end of the specimen and one support beam was provided close to the joint. Load was applied at the mid-span of the slab component which was supported by the connector and one end support (similar to that in Figure 9). Specimens tested under the above arrangement had higher load carrying capacities than those tested using the pure shear rig. Therefore, DSDA20 was tested using the modified arrangement. The failure load of DSDA20 was slightly higher than that interpolated from other tests using the pure shear rig.



(all units in mm)

Figure 8 Modified rig, added support

Since specimen details in the current study are different from those in the previous test program (such as width of specimen, cover

Table 4 Test results of specimens using Staifix DSD75 (DSDB) connectors

Vertical displacement (mm)

Load (kN)	DSDB10*	DSDB20	DSDB30	DSDB40	DSDB50
0	0	0	0	0	0
10	-	0.08	0.13	0.09	0.15
20	-	0.18	0.28	0.20	0.32
26	0.78	0.25	0.35	0.28	0.40
30	0.80	0.29	0.41	0.34	0.47
50	0.90	0.46	0.70	059	0.70
80	1.27	0.76	1.09	0.99	1.04
100	1.60	1.04	1.42	1.30	1.34
140	2.70	1.60	2.30	2.23	5.60
160	4.10	1.68	4.40	4.10	8.20
176	-	-	-	-	13.00
176.9	-	-	-	11.52	
180	7.55	5.39	6.58		
196	15.67	-	-		
200		9.11	8.87		
218		-	17.6		
251		9.48			

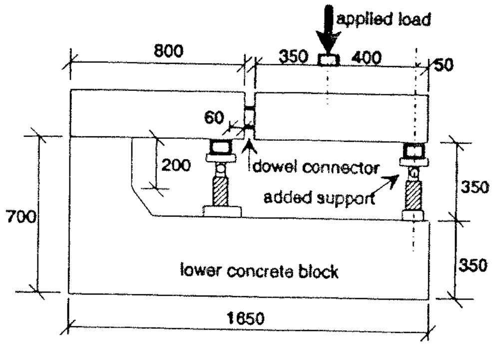
* DSDB10 was tested using pure shear rig (Figure 4)

to reinforcement, etc.), a direct comparison cannot be made. However, the result of DSDA20 indicates that a support close to the joint can enhance the strength of the connection.

Results of DSDB (or Staifix DSD75) Connector Tests

Specimen DSDB10 was tested using the pure shear rig, as shown in Figure 4. For reasons similar to those of testing specimen DSDA20 in the modified test setup, the rests of the DSDB series specimens, i.e. DSDB20, DSDB30, DSDB40 and DSDB50, were tested in a modified rig as shown in Figure 9.

Test results of the DSDB series specimens are given in Table 4. The relationship between load carrying capacity and joint width is shown in Figure 7, which indicates that the load carrying capacity again decreases with an increase in joint width. These results also indicate that when a support is provided close to the joint, the load carrying capacity is higher. The load carrying capacity of DSDB10 is lower than that interpolated from the others tested using the modified rig, as can be seen in Figure 7.



(all units in mm)

Figure 9 Modified rig used in DSDB series (except DSDB10)

5. Discussion of Test Results

Effect of Loading Arrangement

The specimens were tested under three different loading arrangements. The pure shear rig shown in Figure 4 lacks the support near the joint which the other two loading rigs have. If identical specimens were tested using the pure shear rig and those with an additional support near the joint, the one tested under the pure shear rig would be weaker. Because of limitations on the total number of specimens, no identical specimens were tested using different loading arrangements. However, when the test result of a specimen is compared to the interpolated value from the results of specimens tested under another loading arrangement, the comparison confirms that a support at the joint can enhance the load carrying capacity of a specimen.

Failure Mechanism

Once the unreinforced concrete has spalled away, the dowels deform plastically in the manner shown in Figure 10. A close examination of the failed specimens revealed that the surface plate of the connectors shifted from its original location in the direction of loading with its rotational centre located inside the specimen. This observation supports the assumption about the deformed dowel shape in Figure 10.

The plastic hinges do not form at the surface of the joint, but at some distance inside the joint, since they are not supported by reinforced concrete. Therefore, the effective span of the joint (s) is larger than the nominal joint width (j) by an amount (x). x need not be symmetrically arranged within the joint if the support conditions on the two sides differ.

For the geometry shown in the tests, and assuming that four dowels cross each joint, the shear load V is related to the fully plastic moment M_p of the dowel by

$$= \frac{8M_p}{(j+x)} \quad \ldots\ldots (1)$$

and the plastic moment can be obtained from

$$M_p = \frac{d^3 f_y}{6} \quad \ldots\ldots (2)$$

The stainless steel bars used in the connectors have a 0.2% proof strength of 800 N/mm^2; taking this as the yield strength, plastic moments for DSDA and DSDB dowels are 778 kN.mm and 1420 kN.mm respectively.

In the tests of the DSDA series, all specimens except DSDA20 were tested using the pure shear test setup. Values of x can be worked out from these results. The average of all x values (except that of DSDA20) is 31 mm. Since these specimens were tested under the same support condition, the average x value describes the increase in the effective span s due to the spalling of unreinforced concrete. Using the average x in Equation (1), we have

$$= \frac{8M_p}{(j+31)} \quad \ldots\ldots (3)$$

Equation (3) can be used to estimate the load carrying capacity for specimens tested in this series. The result of this estimation is shown in Figure 7 as a line connecting these estimated ultimate load points. The estimated load carrying capacity is very close to the test results for all the specimens in the series. This reveals that the plastic hinge model can predict the actual failure load reasonably well.

A similar analysis on the test results of DSDB specimens (except DSDB10) gives an average x=22 mm. So for specimens in the DSDB series, the load carrying capacity can be estimated from

$$= \frac{8M_p}{(j+22)} \quad \ldots\ldots (4)$$

and the equivalent curve is also shown in Figure 7. This is in reasonable agreement with the test results in the DSDB series. The decreased value of x, for larger dowels, clearly shows the influence of the local support.

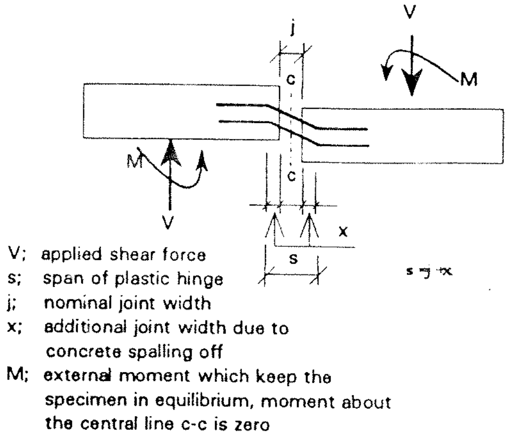


Figure 10 Deformation of dowels after test

The tests conducted in the test programme used a concrete characteristic strength of 25 N/mm^2. This is lower than would normally be used in current site practice where a minimum concrete characteristic strength of at least 30 N/mm^2 would be more normal. Based on the results of the current study and investigations by other organizations, the manufacturer of the connector system has produced a booklet giving technical information of their full product range.

6. Conclusions

The double dowel shear connector system provides a convenient way to transfer shear load in concrete construction at movement joints. Its possible applications and method of use are introduced.

Two types of the shear connector were tested using arrangements which represented severe loading conditions in construction practice. Test results show that the shear connectors are capable of resisting significant loads. The ultimate load values given in Table 3 and 4 are those of specimens with two dowel connectors, and note should be taken of the differing support conditions..

The influence of the support conditions in the tests would be reflected in practical applications by the effect of reinforcement within the slab. It is important that the slab should be reinforced to carry a point load acting in shear through the dowel as close to the front face of the slab as is practicable. The width of the joint assumed for design purposes should take account of any unreinforced (cover) region.

Acknowledgment

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