BEHAVIOUR OF THE "CAZALY HANGER" SUBJECTED TO VERTICAL LOADING

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This paper describes the initial results of a continuing program of research and testing of precast concrete connections conducted at the University of Toronto in co-operation with the Canadian Prestressed Concrete Institute. The purpose of the project was to study the full range of behaviour of the Cazaly hanger connection.

A typical beam to column connection is shown in Fig. 1. The Cazaly hanger consists of three components: a cantilevered top bar which supports the unit containing the hanger; a strap which transfers the vertical load to the bottom of the unit and which, in prestressed members, also serves as anchorage zone reinforcement; and top and bottom anchorage dowels. The basic function of the top dowels is to transfer any horizontal force that acts on the connection. Since this first phase of the program considered the effect of vertical loads only, 40 of the 52 hangers tested did not have top dowels.

The hangers may be divided into three groups according to the purpose of the tests:

1. A pilot series of eight hangers tested to obtain an insight into the probable modes of failure and the variables which might affect hanger capacity.
2. A series of 38 hangers tested to determine the effects of hanger properties on capacity and to observe the behaviour of hangers under load.
3. Tests of six hangers to study the effects of prestressing on hanger strength.

The variables considered in the tests were number and size of bottom dowels, depth of strap, size of strap, concrete strength, ratio of shear span to beam depth, effect of prestress, and position of hanger reaction.

TEST SPECIMENS

Hangers. All specimens were manufactured by various local prestressed concrete plants, and were instrumented, prior to casting, at the Uni-

The Canadian Prestressed Concrete Institute is currently supporting research at the University of Toronto on the 'Cazaly hanger', a particular type of connection used extensively in Canada and described in the Canadian Prestressed Concrete Institute Handbook. In the initial study, 52 connections were tested to determine the behaviour of this type of connection when subjected to vertical loading.

versity of Toronto laboratories. The dimensions and material properties of individual hangers are shown in Table 1. The steel yield stresses were determined either from steel mill reports or from tension tests of standard coupons taken from hangers tested.

Beams. All concrete used in the test beams conformed to the standards set by the individual manufacturer. Three 6 x 12-in. standard test cylinders were cast with each beam and cured the same as the beams under plant conditions. The 28-day concrete cylinder strengths varied from 3430 to 8050 psi. The reinforcing steel used in the beams conformed to ASTM A305 for deformation and to ASTM A15-62T, Hard Grade, for metallurgical properties. The properties of all test beams are shown in Table 2.

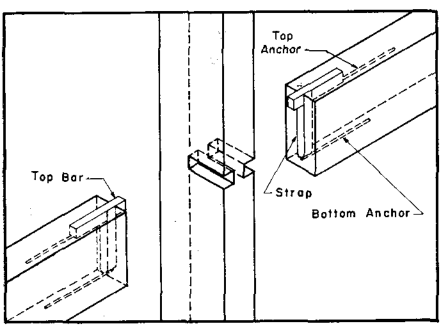


Fig. 1. Typical beam to column Cazaly hanger connection

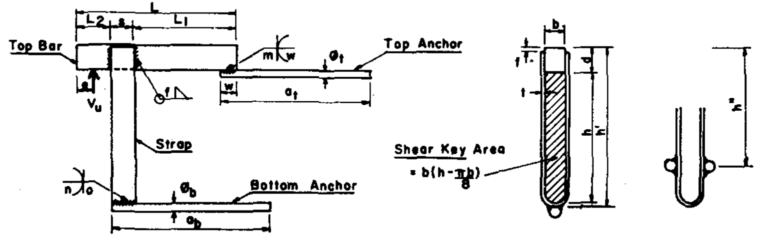
INSTRUMENTATION

Twenty-four hangers were instrumented with Budd metalfilm strain gauges of type C6-121-A mounted on the strap and top bar. The instrumentation varied according to the purpose of the test. Strains were measured directly with the Budd Datran Digital Strain Indicator and typed on a paper tape.

TEST PROCEDURES

The hangers were tested individually. The beam was supported on concrete abutments and the hanger to be tested rested on a steel frame which permitted viewing of the beam end. The test setup for vertical

Table 1. Summary of hanger properties and test results



	Hanger Mark***	Top Bar L (in.)	Top Bar L_1 (in.)	Top Bar L_2 (in.)	Top Bar e (in.)	Top Bar b (in.)	Top Bar d (in.)	Top Bar f (in.)	Strap t (in.)	Strap h' (in.)	Strap h (in.)	Strap h'' (in.)	Strap s (in.)	Bottom Anchor ϕ_b	Bottom Anchor a_b (in.)	Bottom Anchor n (in.)	Bottom Anchor o (in.)	Beam a (ft.)	Beam L' (ft.)	Beam f'_c (psi)	Test Results V_u (kips)
Reinforced Concrete Beams	P-1-A*	15.0	10.50	3.00	1.50	1.5	2.0	1/4	1/4	7.5	5.25	—	1.50	1-#5	21.0	3/8	1.50	2.0	8.0	8040	16.5
	P-1-B*	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	18.2
	P-2-A*	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	1.5	"	"	17.3
	P-2-B*	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	16.0
	P-3-A*	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	3.0	"	"	14.4
	P-3-B*	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	16.1
	P-4-A*	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	4.0	9.0	"	16.7
	P-4-B*	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	2.5	8.0	"	15.5
	T-1-1	16.0	10.00	3.50	1.75	2.0	2.5	1/4	5/16	16.0	13.19	—	2.50	1-#7	18.0	3/8	2.50	4.5	10.0	4910	33.5
	T-1-2	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	33.8
	T-2-3	"	"	"	"	"	"	"	"	10.0	7.19	—	"	"	"	"	"	"	"	5175	23.4
	T-2-4	"	"	"	"	"	"	"	"	16.0	13.19	—	"	—	—	—	—	"	"	"	17.1
	T-3-5	"	"	"	"	"	"	"	"	"	"	—	"	1-#7	18.0	3/8	2.50	"	"	5430	39.3
	T-3-6	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	36.5
	T-4-7	"	"	"	"	"	"	"	"	"	"	—	"	—	—	—	—	"	"	5775	17.9
	T-4-8	"	"	"	"	"	"	"	"	"	"	—	"	—	—	—	—	"	"	"	17.3
	T-5-9	"	"	"	"	"	"	"	"	"	"	—	"	1-#7	18.0	3/8	2.50	"	"	5630	43.4
	T-5-10	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	36.5
	T-6-11	"	"	"	"	"	"	"	"	10.0	7.19	—	"	"	"	"	"	"	"	6350	23.9
	T-6-12	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	23.6
	T-7-13	"	"	"	"	"	"	"	"	16.0	13.19	—	"	"	"	"	"	"	"	7160	43.4
	T-7-14	"	"	"	"	"	"	"	"	"	"	—	"	1-#8	"	"	"	"	"	"	44.3
	T-8-15	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	7500	53.9
	T-8-16	"	"	"	"	"	"	"	"	"	"	14.5	"	2-#5	"	1/4	"	"	"	"	50.3
	T-9-17	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	6375	46.7
	T-9-18	"	"	"	"	"	"	"	"	"	"	"	"	2-#6	"	5/16	"	"	"	"	54.0

	Hanger Mark***	Top Bar L (in.)	Top Bar L_1 (in.)	Top Bar L_2 (in.)	Top Bar e (in.)	Top Bar b (in.)	Top Bar d (in.)	Top Bar f (in.)	Strap t (in.)	Strap h' (in.)	Strap h (in.)	Strap h'' (in.)	Strap s (in.)	Bottom Anchor ϕ_b	Bottom Anchor a_b (in.)	Bottom Anchor n (in.)	Bottom Anchor o (in.)	Beam a (ft.)	Beam L' (ft.)	Beam f'_c (psi)	Test Results V_u (kips)
Reinforced Concrete Beams	T-10-19	16.0	10.00	3.50	1.75	2.0	2.5	1/4	5/16	16.0	13.19	14.5	2.50	2-#6	18.0	5/16	2.50	4.5	10.0	7470	57.2
	T-10-20	"	"	"	"	"	"	"	"	"	"	"	"	2-#7	"	3/8	"	"	"	"	62.4
	T-11-21	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	3.0	8.5	7280	59.4
	T-11-22	"	9.25	"	"	"	"	"	1/4	"	13.25	—	3.25	1-#7	"	"	3.25	4.5	10.0	"	47.5
	T-12-23	"	"	"	0.75	"	"	"	"	"	"	—	"	"	"	"	"	"	"	7220	39.9
	T-12-24	"	"	"	1.75	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	47.7
	T-15-29	"	10.00	"	"	"	"	"	5/16	10.0	7.19	—	2.50	3/4x1-1/2	8.0	1/2	2.50	"	"	6220	21.8
	T-15-30	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	27.3
	T-17-33*	24.0	13.25	4.75	1.00	3.0**	7.0	5/16	3/8	29.0	21.63	27.5	6.00	2-#6	36.0	5/16	3.50	3.5	11.0	6440	156.2
	T-17-34*	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	148.1
	T-18-35	16.0	10.00	3.50	1.75	2.0	2.5	1/4	5/16	10.0	7.19	—	2.50	1-#7	18.0	3/8	2.50	3.0	10.0	6125	30.0
	T-18-36	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	30.7
	T-19-37	"	"	"	"	"	"	"	"	13.0	10.19	—	"	"	"	"	"	"	"	3430	41.9
	T-19-38	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	37.8
	T-20-39	"	"	"	"	"	"	3/16	3/16	16.0	13.19	—	"	"	"	5/16	"	4.5	"	3650	37.4
	T-20-40	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	42.6
	A-1-1	16.0	10.00	3.50	1.75	2.0	2.5	1/4	5/16	12.0	9.19	—	2.50	1-#7	18.0	3/8	2.50	4.5	10.0	5870	31.2
	A-1-2	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	32.6
	A-2-3	"	"	"	"	"	"	"	"	14.0	11.19	—	"	"	"	"	"	"	"	5820	35.3
	A-2-4	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	36.6
Prestressed Conc. Beams	T-13-25	16.0	10.00	3.50	1.75	2.0	2.5	1/4	5/16	16.0	13.19	—	2.50	1-#7	18.0	3/8	2.50	4.5	10.0	5240	50.3
	T-13-26	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	50.3
	T-14-27	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	5200	53.8
	T-14-28	"	"	"	"	"	"	"	"	"	"	—	"	"	"	"	"	"	"	"	56.0
	T-16-31*	24.0	13.25	4.75	1.00	3.0**	7.0	5/16	3/8	29.0	21.63	27.5	6.00	2-#6	36.0	5/16	3.50	3.5	11.0	6640	178.7
	T-16-32*	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	166.5

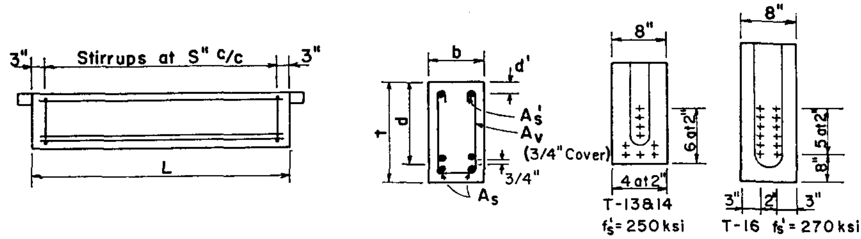
* Hangers With Top Anchors	ϕ_t	a_t (in.)	w (in.)	m (in.)
P-1-A to P-4-B	1-#3	15.0	2.0	1/4
T-16-31 to T-17-34	2-#6	36.0	3.5	5/16

** Top Bar consists of two 1-in. plates spaced 1 in. apart.

*** Explanation Of Hanger Mark
P — refers to a pilot series of eight hangers tested at U. of Toronto
T — refers to hangers tested at U. of Toronto
A — refers to hangers tested at U. of Alberta in Calgary
The first letter is followed by a number used to identify the beam in which the hanger was cast. The third number or letter identifies the hanger itself.

Material Specifications Hanger Component	Steel Spec.	Hanger Mark
Top Bar	CSA G40.12	T-16-31 to T-17-34
	ASTM A7	T-13-25 to T-15-30
	ASTM A36	All remaining hangers
Strap	ASTM A36	All hangers
Top Anchor	ASTM A15 HG	P-1-A to P-4-B
	ASTM A432	T-16-31 to T-17-34
Bottom Anchor	ASTM A36	T-15-29 and T-15-30
	ASTM A432	T-16-31 to T-17-34
	ASTM A15 HG	All remaining hangers

Table 2. Properties of test beams



Beam Mark	No. of Beams	L (ft.)	b (in.)	t (in.)	d (in.)	d' (in.)	A_s	A'_s	A_v	s (in.)
Pilot Series	4	10.0	6	10	8.25	1.44	2-#10	2-#5	2-#3	3
T-1 to T-12, T-15, A-1, A-2	15	12.0	8	20	17.25	1.56	4-#9	2-#5	2-#4	6
T-17	1	14.0	8	34	31.25	1.56	6-#9	2-#5	2-#4	3
T-18	1	12.0	8	14	11.5	1.44	4-#8	2-#5	2-#3	6
T-19	1	12.0	8	17	14.5	1.44	4-#8	2-#5	2-#3	6
T-20	1	12.0	8	20	17.5	1.44	4-#8	2-#5	2-#3	6
T-13, T-14	2	12.0	8	20	14.44	1.56	9-½"ϕ strand 1.30 in.^{2}	2-#5	2-#4	6
T-16	1	14.0	8	34	21.00	1.56	12-½"ϕ strand 1.84 in.^{2}	2-#5	2-#4	3

loading of the hangers is shown in Figs. 2 and 3.

After each load increment, crack development was observed, and in most cases marked, and strain readings were recorded. In one case (hanger T-11-12) the beam failed in compression before the connection. The loading span was then reduced and the hanger loaded to failure.

In many cases (hangers T-1-1, P-3-A, P-3-B, P-4-B, T-13-26, T-13-25, T-14-28) the hanger was twisted in such a way that the top bar rotated about its longitudinal axis, resulting in a hanger load point at the edge of the top bar rather than a line load across the width of the top bar. Since this is typical of actual construction conditions, the hangers were tested with this eccentricity unless the amount of twist exceeded 1/32 in./in., in which case the top bar was shimmed.

DESCRIPTION OF FAILURE

In all of the tests, the ultimate load of the connection was reached when the anchorage of the strap failed. The strength of the concrete and the bottom anchors controlled the hanger capacity, not the strength of the top bar and strap.

Failure Mechanisms. Hangers anchored by a single bottom dowel failed when the combined shearing capacity of the concrete shear key (see Table 1) and the dowel was exceeded. Fig. 4 shows a typical failure condition for a hanger anchored by a single bottom dowel and clearly indicates the function of the concrete key and the dowel.

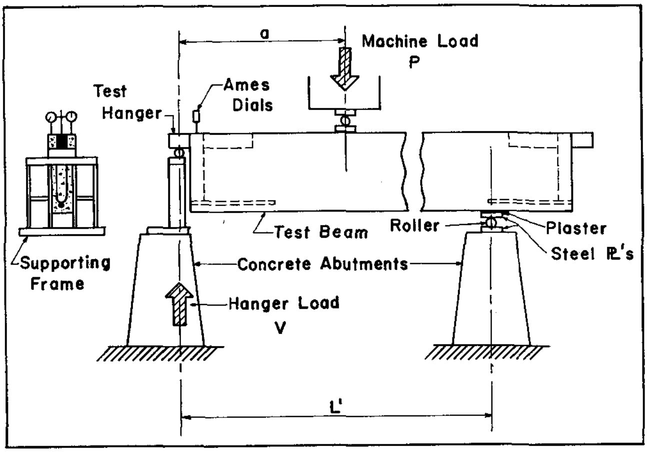


Fig. 2. Loading arrangement

Those hangers anchored by two bottom dowels attached to the side of the strap demonstrated a type of failure as shown in Fig. 5. In this case, the capacity of the hanger depends on the bearing capacity of the concrete above the dowels as well as the shear strength of the concrete key and dowels. The wedging action of these side dowels produces much more severe cracking at the end of the beam compared to the hangers with a single dowel.

The external behaviour of both types of hangers up to the failure load was quite similar. Even with the hanger supporting only the weight of the test beam itself, a portion of the load was transferred to the bottom of the strap. Thus, at very low loads, the combined action of the concrete key and the bottom dowels was effective in transferring load. In both cases, as the load increased, hairline cracks appeared in the concrete on the outside of the strap near the top of the beam. At about one-third ultimate load, that is below the working load, the cracks progressed to the bottom of the strap and, with further increase in load, the whole hanger rose a very small amount with respect to the beam. The ultimate or failure load of the hanger was reached when the concrete key within the strap sheared off on a plane flush with the back of the strap. Fig. 6 shows this shear failure for a hanger without a bottom dowel.

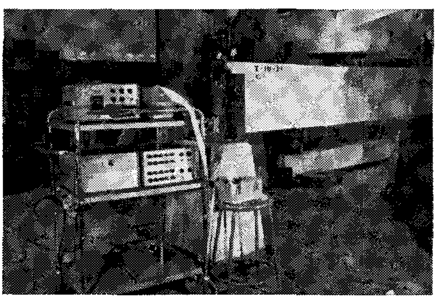
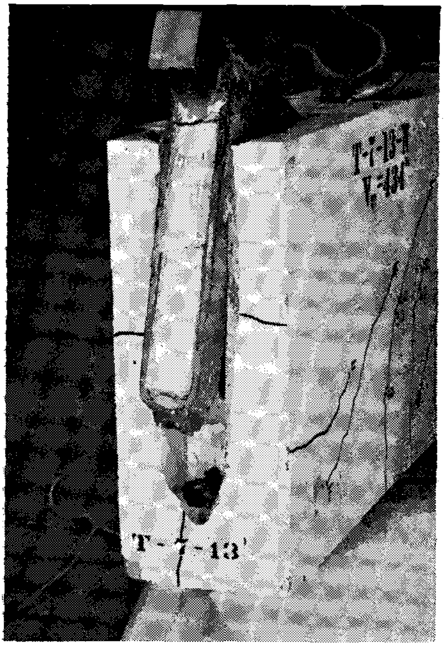


Fig. 3. Test setup and recording equipment

Stresses. Whether or not the bottom dowel, or dowels, share in the transfer of the load to the extent that they have reached their ultimate shear strength prior to the failure of the concrete key is difficult to determine. Neither the concrete key nor the



Fig, 4. Failure of a hanger with a single bottom dowel

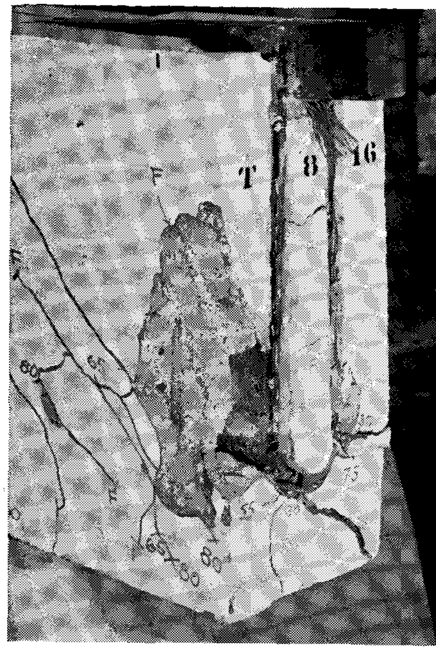


Fig. 5. Failure of a hanger with double bottom dowels

bottom dowel is subjected to pure shear.

The concrete key must resist tensile stresses across the failure planes at the bottom of the strap. The magnitude and distribution of shearing and tensile stresses in the key will depend on a number of factors: concrete properties, size and shape of the key, strap stiffness, size and position of the bottom dowels, and the bond between key and strap.

The bottom dowels will be subjected to bending and tensile stresses as well as large shearing stresses. If the concrete above the dowels were an infinitely rigid material, there would not be any bending stresses; but since the concrete provides an elastic-plastic support, the bending stresses will be significant. However, the tensile stresses due to axial load in the dowel will be small prior to failure since the horizontal force required for equilibrium is small and is shared by both the key and the dowels.

The exact determination of the stresses in the key and dowel which will cause failure is a difficult problem and is beyond the scope of this investigation. For design purposes, an empirical approach to the problem is probably satisfactory.

Deformations. Once the hanger capacity was reached, the load carried in most cases dropped off to a value approximately equal to the shear capacity of the bottom dowels. The hanger continued to carry this load with increasing deformation until either the dowel or the weld between the dowel and the strap ruptured. Fig. 7 is a typical load deformation curve.

The deformations observed prior

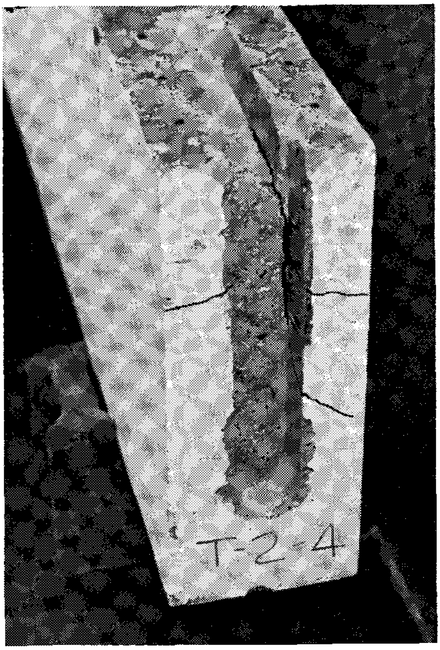


Fig. 6. Failure of a hanger without bottom dowels

to the ultimate capacity of the hangers were small, and behaviour was brittle until the failure of the concrete key. However, providing there is an adequate safety factor in the design of the connection, the hanger would behave in a satisfactory manner.

The ductility of the hangers would be assured if the hanger were designed in such a manner that yielding of the strap preceded the failure of the concrete key.

BEHAVIOUR OF HANGERS UNDER LOAD

Twenty-four of the hangers tested were electrically strain gauged to provide information on the behaviour of the hangers under load. Three aspects of the load transferring function of the hanger are of particular interest: first, the type of compressive stress block developed below the top bar at its interior end;

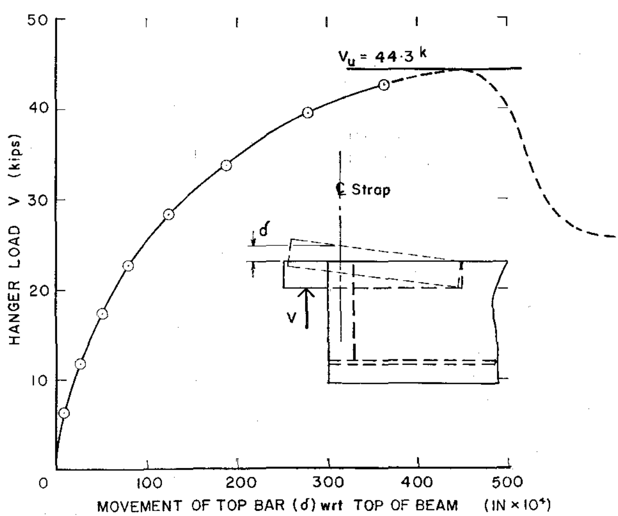


Fig. 7. Typical curve of hanger load vs top bar movement.

second, the effect of bond on the forces in the strap; and third, the horizontal shear force in the strap.

Action of Top Bar. Hangers T-3-5, T-3-6, T-5-9, and T-5-10 were strain gauged as shown in Fig. 8. Tables 3 and 4 summarize the strain readings taken for hanger T-3-5 and the calculated stress resultants and moments at the gauge sections. Since gauge No. 6 was inoperative during the test, it was necessary to extrapolate to obtain the strains shown in Table 3.

The average shear between gauge sections on the top bar is the difference in moment between the sections divided by the distance between the sections. C refers to the average shear between sections 5-6 and 11-12; g is the distance in inches from the interior end of the top bar to the point at which a concentrated force of the same magnitude as C must act in order to produce the measured moment at section 5-6. A certain amount of bond acts on the top bar and the strap above the level of section 1-4. This bond is referred to as vertical bond B_v and is equal to $V + C - T$.

The results indicate that within reasonable limits of experimental error and variation in material properties the shear in the top bar is constant between sections 5-6 and 11-12 and equal to C.

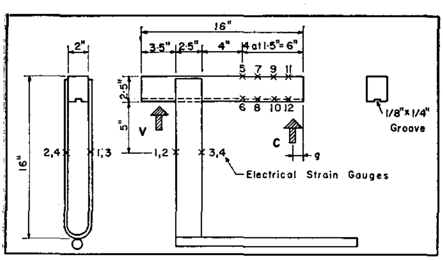


Fig. 8. Location of strain gauges on hangers T-3-5, T-3-6, T-5-9, T-5-10

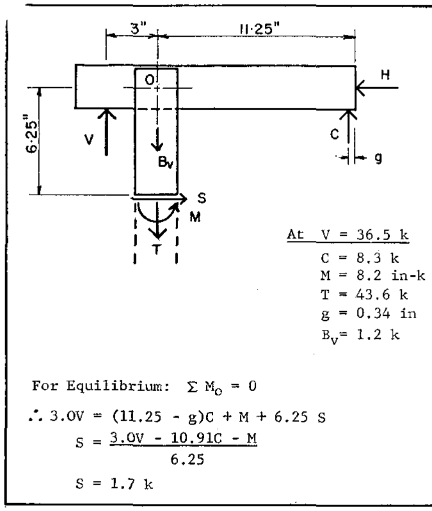


Fig. 9. Free body diagram of hanger T-3-5

It may be concluded from this observation that the reaction to hanger load under the internal end of the top bar is limited to a position between gauge section 11-12 and the end of the bar. In fact, g is the distance of this resultant internal reaction from the end of the top bar and C is its magnitude. In the case of hanger T-3-5, the internal resultant reaction, C, moved closer to the end as the load was increased. Just prior to failure, it acted at a point approximately ¼ in. from the end. The position and magnitude of C will, however, depend on the length of the top bar and the area of the strap. A well proportioned hanger should fail by yielding of the strap. This condition would ensure that the internal reaction was located near the end of the top bar.

Considering the known forces acting on the top bar and the portion of the strap above section 1-4, the shear force in the strap required to keep the hanger in equilibrium may be determined. Fig. 9 shows a sketch of hanger T-3-5 with all the known

Table 3. Strains in hanger T-3-5 (microin./in.)

V (kips)	Gauge Number											
	1	2	3	4	5	6	7	8	9	10	11	12
0.8	−34	11	26	19	−9	6	−8	3	−4	2	−1	−3
6.3	197	176	145	82	−92	75	−69	45	−33	25	−14	−3
11.8	416	357	220	141	−190	145	−141	100	−89	55	−38	10
17.3	622	540	299	200	−295	230	−219	164	−141	96	−61	31
22.8	858	747	375	257	−416	335	−313	245	−203	148	−94	64
28.3	1070	974	471	313	−541	452	−402	327	−262	200	−133	74
33.8	1295	1269	587	353	−697	612	−518	443	−325	273	−160	109
36.5	1385	1404	651	405	−785	710	−589	515	−373	323	−172	134

Note: compressive strains are negative

forces acting on it when the hanger was subjected to a load $V = 36.5$ kips. This value of strap shear is of the same order of magnitude as that measured directly during the tests on hangers T-7-13 to T-12-24. It indicates that the tension force in the bottom dowel immediately prior to failure is quite small. The actual value of this force will depend on the bending stiffness of the strap and the effectiveness of the bond between the concrete key and the strap.

Action of the Strap. Twelve hangers, T-7-13 to T-12-24, were electrically strain gauged as shown in Fig. 10. Tables 5 and 6 summarize the strain readings taken for hanger T-7-14 and the calculated stress resultants at the gauged sections. Only two gauge sections were used on the top bar with these hangers since the moments at only two sections are required to define the magnitude and position of the compressive stress resultant C.

Table 4. Forces in hanger T-3-5

V (kips)	T_{1-4}	M_{1-4}	M_{5-6}	M_{7-8}	M_{9-10}	M_{11-12}	S_{5-7}	S_{7-9}	S_{9-11}	C	g	B_v
0.8	0.2	−0.3	0.5	0.3	0.2	−0.1	0.1	0.1	0.2	0.1	2.03	0.7
6.3	6.8	0.7	5.2	3.6	1.8	0.3	1.1	1.2	1.0	1.1	1.18	0.6
11.8	12.8	1.9	10.5	7.5	4.5	1.5	2.0	2.0	2.0	2.0	0.75	0.9
17.3	18.8	3.1	16.4	12.0	7.4	2.9	3.0	3.0	3.0	3.0	0.54	1.5
22.8	25.3	4.6	23.5	17.4	11.0	4.9	4.0	4.3	4.0	4.1	0.30	1.6
28.3	32.0	5.9	31.0	22.8	14.4	6.5	5.5	5.6	5.3	5.5	0.32	1.7
33.8	39.7	7.7	40.9	30.0	18.7	8.4	7.2	7.6	6.9	7.2	0.34	1.3
36.5	43.6	8.2	46.7	34.5	21.8	9.6	8.1	8.5	8.1	8.3	0.34	1.2

V = hanger load (kips)

T_{1-4} = tension in strap at gauge section 1-4 (kips)

M_{1-4} = moment in strap at gauge section 1-4 (in.-kips)

S_{5-7} = shear between gauge sections 5-6 and 7-8 (kips)

C = reaction at interior end of top bar (kips)

g = distance of C from interior end of top bar (in.)

B_v = vertical bond on hanger above gauge section 1-4 (kips)

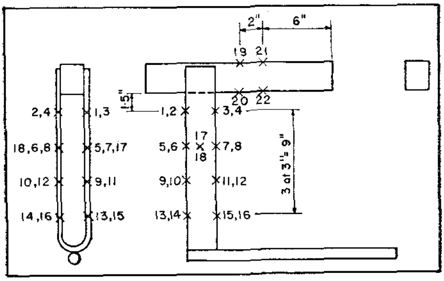


Fig. 10. Location of strain gauges on hangers T-7-13 to T-12-24

Particularly interesting is the plot of the tension at the four sections on the strap versus hanger load (Fig. 11). The vertical distance between the curves of tension at a section is simply the change in tension between the sections. This change in tension is the result of bond along the strap. The plot indicates that small loads are taken almost entirely by bond on the strap, but as the load increases, the bond is broken, initially at the top of the strap and finally all the way to the bottom. Thus, just prior to failure, the entire hanger load is transferred to the concrete key and the dowel anchorage at the bottom of the strap.

Strain readings taken at section 1-4 indicate that beyond a hanger load of 19 kips the tension at section 5-8 is greater than at 1-4. Since this is unlikely and since this same trend was apparent in all 12 hangers, it was assumed that the four strain readings at section 1-4 were affected by localized stress disturbance due to the strap weld 1½ in. away. At the hanger load of 19 kips, bond on the strap between sections 1-4 and 5-8 has been broken and, therefore, for higher loads the tension at these sections must be the same.

A bending moment diagram for the strap indicates that there is a point of inflection in the lower half of the strap. This is shown in Fig.

Table 5. Strains in hanger T-7-14 (microin./in.)

	Gauge Number										
V (kips)	1	2	3	4	5	6	7	8	9	10	11
0.8	44	52	−11	−7	18	31	15	10	3	7	22
3.6	134	172	−12	−10	44	70	46	63	14	29	48
9.1	413	486	−80	−70	170	228	127	148	49	106	184
14.6	743	835	−166	−160	365	446	186	202	126	209	352
20.0	1038	1174	−228	−248	585	684	236	241	247	345	510
25.6	1300	1408	−276	−283	818	918	272	290	387	512	646
31.0	1548	1798	−288	−225	1072	1130	322	373	599	742	778
36.8	1794	2252	−216	−89	1504	1486	316	449	1012	1143	803
42.6	1774	4550	−65	−28	1772	1634	452	628	1332	1396	840
V (kips)	12	13	14	15	16	17	18	19	20	21	22
0.8	40	4	6	4	10	0	2	−16	16	−10	12
3.6	70	7	16	13	27	−1	6	−63	53	−32	29
9.1	211	27	65	62	155	10	21	−178	156	−108	96
14.6	375	70	122	233	346	16	37	−300	259	−194	184
20.0	523	127	185	447	562	30	69	−440	424	−298	294
25.6	649	196	272	680	787	49	113	−597	592	−420	424
31.0	744	370	454	886	958	82	180	−782	798	−568	584
36.8	808	652	747	1112	1132	165	288	−1000	1076	−750	798
42.6	875	1020	1072	1124	1148	282	372	−1220	1374	−963	1035

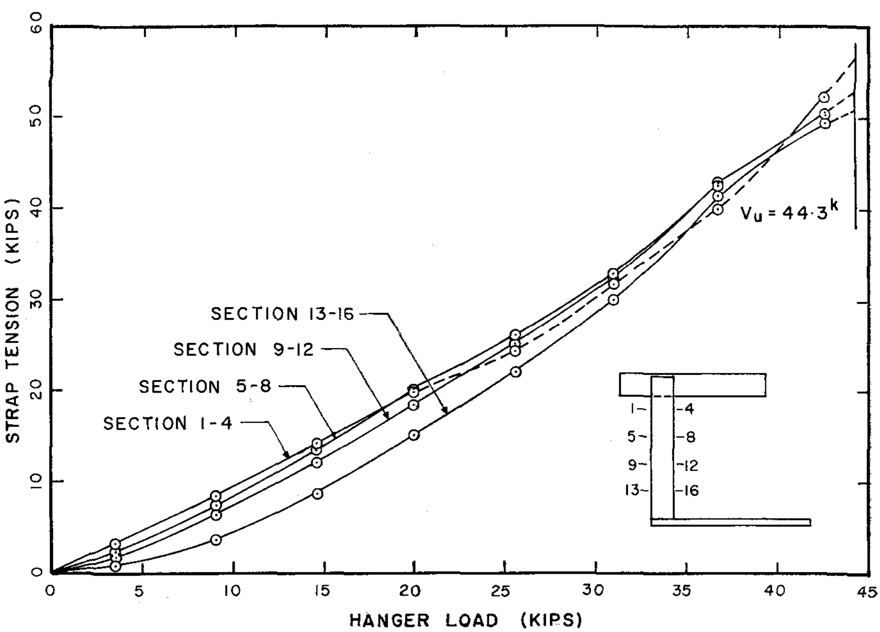


Fig. 11. Tension in the strap vs hanger load for hanger T-7-14

12 where the moment diagram for the strap of hanger T-7-14 has been plotted for several values of hanger load. The reverse moment is a result of the combined action of the large eccentric vertical force and the small horizontal force at the bottom of the strap. At loading stages approaching ultimate hanger load, the outside fibre of the strap near the top bar began to yield and, therefore, the moment capacity of the strap section was reduced. If the hanger capacity had been governed by the yield strength of the strap, the magnitude of the moment and horizontal shear force in the strap just prior to complete yield of the strap would have been close to zero.

A plot of the horizontal shear in the strap of hanger T-7-13 at gauge section 5-8 versus hanger load is shown in Fig. 13. The values of shear shown in the graph have been calculated directly from the biaxial strain readings obtained with gauges 17 and 18. These values agree well with those obtained indirectly from the change in moment between gauge sections on the strap. The graph indicates two things:

1. The maximum value of the horizontal shear in the strap was 2.54 kips which is only 8 percent of the tensile yield capacity of the No. 7 bottom dowel.
2. The shear in the strap drops off after initial yielding of the strap.

Summary. Considering the behaviour of the hanger as a unit, the hanger load is applied to the external cantilever portion of the top bar. The bar is kept in equilibrium by pressure from the concrete at its interior end and by tension, moment, and shear in the strap. For top bars of normal proportions, the concrete reaction may be considered to act at the end of the bar even for low

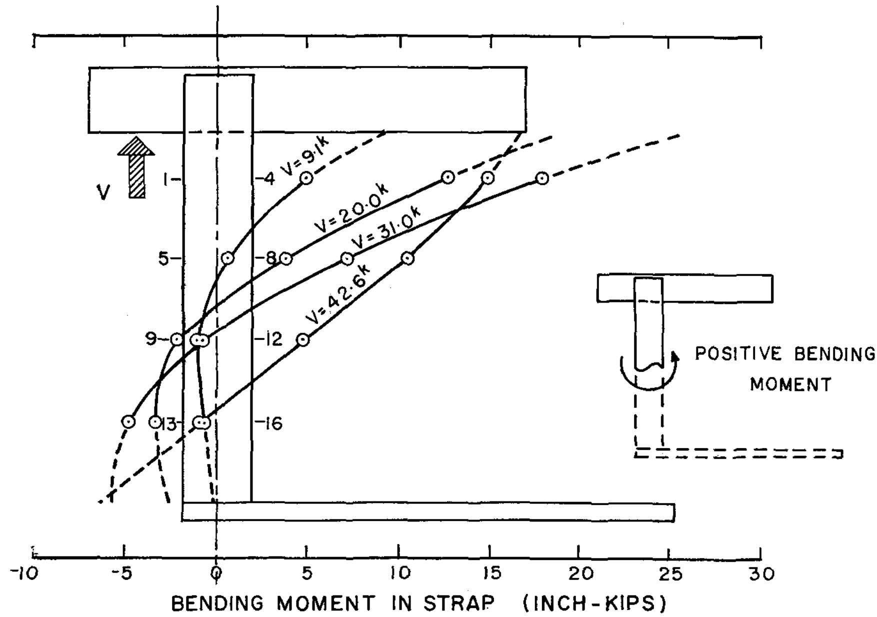


Fig. 12. Bending moment diagrams for the strap of hanger T-7-14 at various hanger loads

loads.

Assuming a load factor of 2.5, bond carries up to 30 percent of the strap tension at working loads. Just prior to failure, however, bond on the strap has nearly completely broken down and the full strap tension is carried by the concrete key and bottom dowels.

If the strap is properly anchored such that yielding of the strap determines the ultimate capacity of the hanger, the moment and shear in the strap will be close to zero. If, however, the strap has not even partially yielded prior to failure of the strap anchorage, the moment and shear in the strap will depend on the relative stiffness of the top bar and the strap.

FACTORS AFFECTING HANGER CAPACITY

The factors studied were those which influenced the strap anchorage capacity since this limited the strength of all the hangers tested in this series.

Bottom Dowels. Table 7 shows the change in capacities for three types of similar hangers. The only variables were the size of the bottom dowels and the concrete strength.

The average concrete strength of the hangers with the single No. 7 bottom dowel was approximately the same as for the hangers without a bottom dowel. Therefore, the increased capacity of 119 percent is due entirely to the No. 7 dowel. The hangers with a No. 8 dowel are 29 percent stronger than the hangers with a No. 7 dowel due to an increase in concrete strength (31 percent) and steel area (32 percent).

Six hangers were tested with double bottom dowels. The size of the bottom dowels and the concrete strength were the only differences between them.

The capacity of the hanger increased 15 percent when the dowels were changed from No. 5 to No. 6. Concrete strength remained constant and steel area increased 42 percent. When the No. 5 dowels were changed to No. 7, the strength increased by 26 percent. The increase in capacity in this case was due to an increase in steel area (94 percent) and concrete strength (6 percent).

Depth of Hanger. The depth of the hanger had quite a significant effect on the capacity of the connections. Hangers were tested that were identical in all respects except for the depth of the strap, which varied from 10 to 16 in., the concrete strength, which varied a maximum of 7 percent, and the beam depth *t*, which varied from 14 to 20 in. Table 8 summarizes these results. The result of the tests on 16-in. hangers is given in Table 7.

The test data demonstrate the dependence of hanger strength on depth. Fourteen hangers of various depths were cast into similar 20-in. deep beams. A change in hanger depth from 16 to 10 in. (44 percent reduction in concrete shear key area) resulted in a capacity reduction of 38 percent even though the concrete strength increased by more than 6 percent.

Four other hangers (two 10-in. and two 13-in. deep) were cast into beams 4 in. deeper than the hangers themselves. In this case, the change in depth from 16 to 13 in. actually increased the capacity of the hangers slightly (5 percent) even though the concrete strength was reduced by 39 percent. A further reduction in hanger depth to 10 in. resulted in a capacity reduction of 24 percent

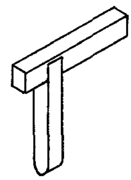
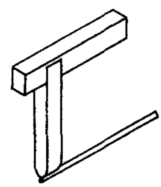
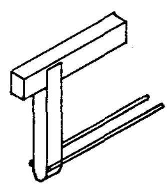
Table 6. Forces in hanger T-7-14

	Tension in Strap				Moment in Strap			
V (kips)	T_{1-4}	T_{5-8}	T_{9-12}	T_{13-16}	M_{1-4}	M_{5-8}	M_{9-12}	M_{13-16}
0.8	0.9	0.8	0.8	0.3	0.5	0.1	−0.2	−0.0
3.6	3.2	2.5	1.8	0.7	1.5	0.0	−0.4	−0.1
9.1	8.5	7.6	6.2	3.5	5.0	0.6	−1.1	−0.6
14.6	14.2	13.6	12.0	8.7	9.0	2.0	−1.8	−1.8
20.0	19.7	19.8	18.3	15.0	12.7	3.7	−2.1	−3.3
25.6	24.3	26.0	24.9	21.9	15.4	5.5	−1.9	−4.7
31.0	31.9	32.8	32.4	30.2	18.0	7.1	−0.9	−4.8
36.8	40.0	42.5	42.7	41.3	18.0	10.5	2.6	−4.0
42.6	52.2	50.4	50.3	49.4	15.0	10.5	4.8	−0.8

	Forces in Top Bar					Shear in Strap		
V (kips)	M_{19-20}	M_{21-22}	C	g	B_v	S_{1-5}	S_{5-9}	S_{9-13}
0.8	1.0	0.7	0.2	1.60	0.1	0.1	0.1	−0.1
3.6	3.6	1.9	0.9	3.78	1.2	0.5	0.1	−0.1
9.1	10.4	6.4	2.0	2.86	2.6	1.5	0.6	−0.2
14.6	18.0	11.8	3.1	2.24	3.6	2.3	1.3	0.0
20.0	27.0	18.5	4.2	1.65	4.5	3.0	1.9	0.4
25.6	37.1	26.4	5.4	1.11	4.9	3.3	2.5	0.9
31.0	49.4	36.0	6.7	0.62	4.9	3.6	2.7	1.3
36.8	64.9	48.4	8.2	0.14	2.5	2.5	2.6	2.2
42.6	78.3	62.4	8.0	−1.85	0.2	1.5	1.9	1.9

See Table 4 for an explanation of symbols

Table 7. Summary of the influence of the bottom dowel on hanger capacity

HANGER MARK	V_u (kips)	f'_c (psi)	SIZE OF DOWELS	TYPE OF HANGER
T-2-4	17·1	5175	-	
T-4-7	17·9	5775	-	
T-4-8	17·3	5775	-	
AVERAGE	17·4	5575		NO BOTTOM DOWEL
T-1-1	33·5	4910	# 7	
T-1-2	33·8	4910	# 7	
T-3-5	39·3	5430	# 7	
T-3-6	36·5	5430	# 7	
T-5-9	43·4	5630	# 7	
T-5-10	36·5	5630	# 7	
T-7-13	43·4	7160	# 7	
AVERAGE	38·1	5590	# 7	
T-7-14	44·3	7160	# 8	
T-8-15	53·9	7500	# 8	
AVERAGE	49·1	7330	# 8	ONE BOTTOM DOWEL
T-8-16	50·3	7500	# 5	
T-9-17	46·7	6375	# 5	
AVERAGE	48·5	6940	# 5	
T-9-18	54·0	6375	# 6	
T-10-19	57·2	7470	# 6	
AVERAGE	55·6	6920	# 6	
T-10-20	62·4	7470	# 7	
T-11-21	59·4	7280	# 7	
AVERAGE	60·9	7375	# 7	TWO BOTTOM DOWELS

NOTE: All Beams 8"X 20"
All Hangers Have Same Size Strap & Top Bar

even though there was an increase in concrete strength of 79 percent.

From these results we may make three observations:

1. The capacity of a hanger depends more on the depth of the hanger than on the strength of the concrete.
2. A shallow hanger has greater strength when cast into a shallow beam than when cast into a deep beam.
3. The reduction in hanger capacity is not a linear function of depth, as is shown in Fig. 14.

The second and third observations may be explained by a consideration of the stresses in the concrete shear key. It is probable that the shear stresses in the concrete key are concentrated at the bottom of the strap and that this concentration increases with an increase in the distance between the bottom of the strap and

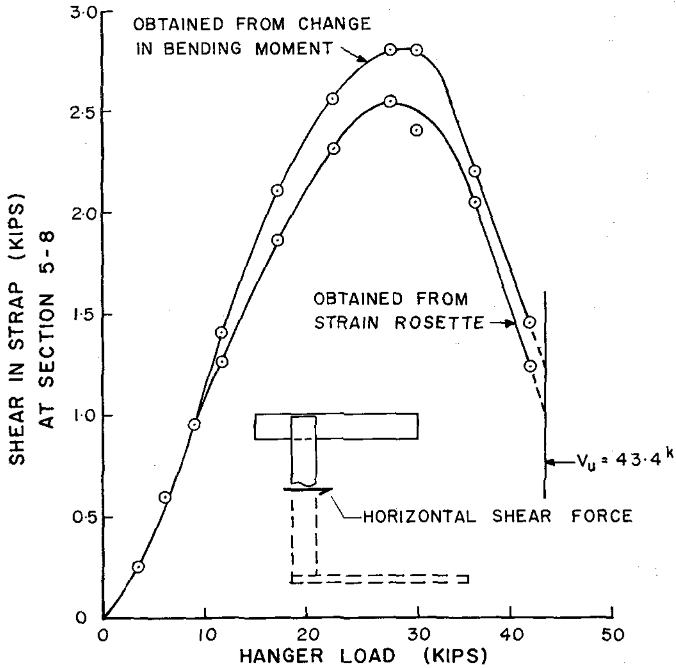


Fig. 13. Horizontal shear in the strap vs hanger load for hanger T-7-13

the position of the longitudinal beam reinforcement. The tensile stresses at the bottom of the shear key will also increase as the strap becomes shorter and stiffer. These two effects will undoubtedly reduce the hanger capacity.

Concrete Strength. Although insufficient tests have been carried out to define the dependence of hanger ca-

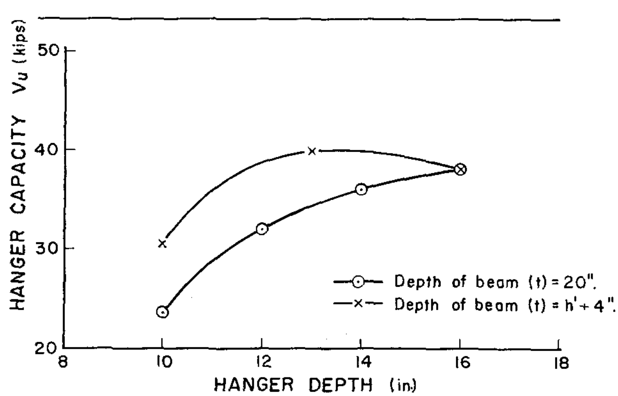
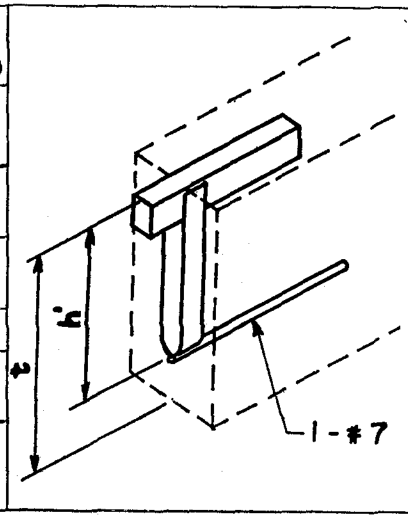


Fig. 14. Curve of hanger capacity vs hanger depth

Table 8. Summary of the influence of depth on hanger capacity

Hanger Mark	h' (in.)	t (in.)	f'_c (psi)	V_u (kips)
T-2-3	10	20	5175	23.4
T-6-11	10	20	6350	23.9
T-6-12	10	20	6350	23.6
Average			5960	23.6
A-1-1	12	20	5870	31.2
A-1-2	12	20	5870	32.6
Average			5870	31.9
A-2-3	14	20	5820	35.3
A-2-4	14	20	5820	36.6
Average			5820	36.0
T-1-1 to T-7-13	16	20	5590	38.1
T-18-35	10	14	6125	30.0
T-18-36	10	14	6125	30.7
Average			6125	30.4
T-19-37	13	17	3430	41.9
T-19-38	13	17	3430	37.8
Average			3430	39.9



Note: All beams 8 in. wide

pacity on concrete strength, there is certainly a definite trend indicated in the test data. With higher concrete strengths, the capacity of the hangers increased. Table 7 shows that hangers T-5-9 and T-5-10 were 19 percent stronger than hangers T-1-1 and T-1-2. The increased strength can be attributed to the 15 percent higher strength concrete.

The hangers with double dowels did not show as great an increase in strength. Hanger T-8-16 displayed only an 8 percent increase in capacity over hanger T-9-17 with an 18 percent increase in concrete strength. These figures can be accepted only as trends since the number of tests involving only variation in concrete strength were too few to define the limits of experimental error. Other variables, such as the depth of the strap, have a greater effect on the capacity of this connection than does a change in concrete strength.

Effect of Prestress. Since the hanger capacity depends on the strength of the concrete shear key, it is not surprising that any prestressing will increase the hanger's ultimate capacity. Four hangers, T-13-25 to T-14-28, identical to hangers T-1-1 to T-7-13 in Table 7, were tested with beams prestressed as shown in Table 2. The average hanger capacity was 52.6 kips with an average concrete strength of 5230 psi. This represents an increase in ultimate load of 38 percent over those hangers cast with normal reinforcement. The concrete strength in the prestressed beams was 6 percent lower than in the reinforced specimens. The prestress force in this case was sufficient to produce a compressive stress of 2840 psi at the bottom fibre and a tensile stress of 410 psi at the top fibre, when acting alone.

The four high capacity hangers (T-16-31, T-16-32, T-17-33, T-17-34) did not display as great an increase in capacity with prestressing. Hangers T-17-33 and T-17-34 which were cast into a reinforced beam with $f_c' = 6440$ psi failed at an average load of 152.1 kips. The average ultimate capacity of hangers, T-16-31 and T-16-32, cast in prestressed beams, was 172.6 kips. This 13 percent increase in load can be attributed almost entirely to the prestressing force which produced a compressive stress of 1860 psi at the bottom fibre and a compressive stress of 320 psi at the top fibre. The arrangement of prestressing and reinforcing steel for these two beams is shown in Table 2.

The prestressing force in the large hangers had only one-third as great an effect on the ultimate capacity of the hangers as did the prestressing force in the smaller hangers, even though all the strands passed through the concrete key. This can be partially explained by the fact that the average stress, due to prestressing, was 12 percent greater in the smaller beams. It is more likely, however, that the capacity of the large hangers is more dependent on the effectiveness of the two bottom dowels than on the strength of the concrete shear key, i.e., the dowel anchorage fails before the concrete key is sheared off.

Shear Span Ratio. In the pilot series, eight identical small hangers were tested with shear span ratios a/d varying from 2.18 to 5.82. The results of these tests are summarized in Table 2. All beams had a concrete strength of 8040 psi and a depth to tension reinforcement d of 8.25 in. Since the results indicate that there is no significant variation in hanger capacity with change in shear span, the remaining tests did not include this ratio as a variable.

Size of Strap and Position of Hanger Load. Hangers T-11-22, T-12-23 and T-12-24 were tested with a strap width of 3¼ in. rather than 2½ in. All other properties of the three hangers were the same as hangers T-1-1 to T-7-13 in Table 7. Hangers T-11-22 and T-12-24 were tested with the hanger load 1¾ in. from the end of the top bar and hanger T-12-23 was tested with the load ¾ in. from the end.

The average failure load for hangers T-11-22 and T-12-24 was 47.3 kips. This load is 24 percent greater than the average failure load for the hangers with the 2½-in. strap. The average concrete strength of these two hangers, however, was 30 percent greater than the average concrete strength for the seven hangers with the 2½-in. strap. The bearing stress of the strap on the concrete key was reduced by 30 percent with the wider strap. It was, therefore, the combination of the greater concrete strength and the reduced bearing stress, which implies a reduced concentration of shear stress at the bottom of the concrete key, that gave these hangers their increased capacity. This provides added evidence that the strength of the hanger depends on the capacity of the concrete key to resist shear.

When the hanger load point is moved closer to the end of the top bar, the tension, moment and shear in the strap and the moment in the top bar are increased, thereby reducing the ultimate load. In the case of hanger T-12-23, the outward movement of the support by 1 in. resulted in a capacity reduction of 7.8 kips, or 16 percent of the capacity of hanger T-12-24. This capacity reduction was due to an increase in the maximum strap moment of 34 percent and an increase in strap tension of 7 percent.

Hangers T-20-39 and T-20-40, sustained an average load of 40 kips before failure, even though they had a concrete strength 35 percent less than hangers T-1-1 to T-7-13 in Table 7, which failed at an average load of 38.1 kips. This greater capacity can be attributed to the more flexible strap which was made from 3/16-in. plate. The strap of hangers T-1-1 to T-7-13 was 5/16 in. thick. The thinner strap required a smaller horizontal force to anchor it at the bottom. The tensile stress in the concrete key was, therefore, reduced and the capacity of the hanger increased. This result confirms the fact that the strap should be made as flexible as possible, consistent with safety.

CONCLUSIONS

Any beam-to-column connection is subjected to horizontal and vertical forces. In this paper, the behaviour of the Cazaly hanger, when subjected to vertical loading only, is discussed, and the results presented should be considered in this light. The importance of horizontal forces on the behaviour of connections is obvious, and there can be no general conclusions or design procedure that does not take these forces into account.

A study to determine the effect of the horizontal forces on the behaviour of the Cazaly hanger is currently under way at the University of Toronto as the second phase of the connection research program. The authors feel that any design recommendations should await the results of this study.

ACKNOWLEDGMENTS

This project was jointly supported by the Canadian Prestressed Concrete Institute and the University of Toronto. The authors would like to express their gratitude to the prestressed concrete industry in Canada for its excellent support and cooperation and to Professor R. Loov of the Civil Engineering Department of the University of Alberta in Calgary for testing the four "A" series hangers as part of this program. Special thanks are also due Mr. Michael Hogan of the Civil Engineering Department of the University of Toronto who was responsible for the computer programs used to analyze the numerous material strains recorded.

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