

ENCLOSURE 2

DRAFT

Effect of Existing Cracks on  
Strength of Reinforced Concrete Members

*Draft -  
This is part 1 & was  
given to Kinaldi on 12/30.  
Part 2 will be done  
Monday 1/4.  
Rog*

A Report to

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by

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### Axial Compression

It is of interest to consider the strength of the same prism (with existing cracks) subjected to axial compression as shown ideally in Fig. 2. The prism is assumed to be loaded axially through stiff bearing plates so that the overall deformations in the concrete and the steel are the same.

Given that the existing cracks are not so wide as to lead to local instability of the bars or overall instability of the entire element, it can be inferred from a knowledge of the stress-strain properties of the materials involved that the reinforcement at the cracks will eventually be strained sufficiently to close the cracks. After that event, large compressive stresses will be developed in the concrete leading typically to failure initiated by spalling of the concrete. Whether this "reseating" process affects the strength of the concrete or of the reinforced concrete section can best be determined by experiment.

Several series of tests of reinforced concrete columns were reported by Richart and Brown (1) in the course of an experimental study which was to lead to the fundamental principles of reinforced concrete column design used today. One of these series, Series 3, was dedicated to the investigation of the effect of sustained loading on column strength. A group of tied and spirally reinforced columns, 5 ft long by 8-in. round (Fig. 3), were subjected to a sustained service load for approximately one year. A parallel group of columns were stored for the same period without any load. Changes in steel stress, calculated from measured strains, observed for the loaded and unloaded columns are illustrated in Fig. 4. The

## Introduction

Reinforced concrete structures are often cracked before the application of the load for which the structure has been proportioned. This note has been prepared to discuss the influence of such "precracks" on structural strength.

Four simple conditions are considered: (1) axial tension, (2) axial compression, (3) bending, and (4) shear. The first condition is discussed not because it requires discussion, but because it represents a fundamental case and does illustrate the basic premise of design in reinforced concrete.

## Axial Tension

A hypothetical case of a reinforcing bar embedded along the axis of a prism of concrete is considered in Fig. 1. Application of an axial tension on the bar will eventually cause cracking of the concrete at a number of sections as shown.

The basic premise of design in reinforced concrete is that all normal tensile forces are resisted entirely by reinforcement. If the element in Fig. 1 had been designed to carry a certain axial tensile force, all the force would have been assigned to the reinforcement. Consequently, whether these cracks form as the tensile force is applied or whether they had occurred earlier as a result of volume-change or stress effects is of no consequence to the proper functioning of this structural element. Cracking of the concrete would affect only the initial stiffness.

accumulated strain at the end of the observation period was approximately 0.008 in the loaded columns.

Richart and Brown report that

"because of the arrangement of the time-loading rigs, it was necessary to release the loads and to remove the columns from the rigs before placing them in the testing machine. This release of load permitted a recovery of the large elastic strains in the steel and resulted in the formation of tension cracks in the concrete, generally 10 to 12 in. apart. The columns were tested at once, and strain measurements showed that when the applied load had reached the value of the one-year sustained load, the cracks had closed, and the steel and concrete strains corresponded closely with those measured under the spring [previous sustained] loading."

Richart and Brown did not report crack widths. The widths may be inferred to be approximately 0.01 in. from the strains indicated in Fig. 4 and the reported crack spacing. No cracks were observed in the columns without load.

Measured strengths of the columns with and without sustained loading are compared in Table 1 reproduced directly from Reference 1. The last column in the table indicates the ratios of the observed strengths of columns with sustained load (which had cracks)  $P_T$  to the observed strengths of comparable columns which had not been previously loaded (and which did not have cracks)  $P_N$ . The ratio is observed to vary from 0.86 to 1.15 with an overall mean value of 1.0 with a coefficient of variation of 6.2 percent. Richart and Brown concluded that, against the background of expected scatter in such test data, there was no significant difference between the strengths of the two groups of columns.

### Bending

A simple and practical model to interpret the flexural strength of a reinforced concrete section is provided by analogy to a structural steel wide-flange section with a thin web. Resisting moment is generated by a couple formed by tensile and compressive forces in the "flanges" of the section as shown schematically in Fig. 5. The tensile force is provided by the steel and the compressive force by a concrete-steel composite, quite similar to the case in Fig. 2. From this interpretation and the information supplied above, it follows that existence of cracks perpendicular to the bars, whatever the cause, would not reduce the flexural strength of the section. A common experimental demonstration of this is provided by the response of a reinforced concrete beam subjected to load reversals. As the beam is cycled cracks develop (shown ideally in Fig. 7). These cracks do not prohibit the beam from developing moments compatible with the strength of the section calculated on the assumption of "first loading."

### Shear

Vecchio (4) reported a series of 30 tests to investigate the force-deformation properties of reinforced concrete laminas subjected to in-plane forces. The results of this investigation permit a comparison of the strength of reinforced concrete laminas which have been cracked before shear loading with the strengths of laminas which had no visible cracks before loading. (The term "lamina" is used here for a slab to avoid association with "slab shear strength" which refers typically to out-of-plane forces.)



Fig. 10. (The term  $\rho_t$  refers to the lower of the reinforcement ratios in the two orthogonal directions.)

One specimen, PV 26, was cracked in biaxial tension before loading in shear. The cracks were obtained by applying forces equal to 60 percent of the calculated yield stress of the reinforcement simultaneously in each direction (of the reinforcement parallel to the edges of the specimen). Shear forces were applied after release of the tensile forces. As represented in Fig. 10 by a solid circle, this specimen developed a strength comparable to that of the monotonically loaded specimens.

Another specimen, PV 30, was also initially cracked in biaxial tension in the same manner as it was done for PV 26. However, PV 30 was then subjected to shear force reversals. The nominal stress level was increased in 100-psi increments starting from 125 psi. At each stress level, the stress was cycled ten times. The maximum shear stress developed by PV 30 is also shown by a solid circle in Fig. 10. It is evident that the strength of the specimen was not affected by existence of initial cracks and by the stress reversals.

The observed results can be anticipated by interpreting the response of the lamina in terms of the simple "truss mechanism" illustrated in Fig. 11. The diagonal truss elements operate in a manner similar to the tension and compression elements shown in Fig. 1 and 2. The stiffness of the lamina would be expected to decrease because of cracks existing before load application, and it does. But given that the "precracks" do not affect strength in cases illustrated in Fig. 1 and 2, it follows







# STRENGTH OF COLUMNS OF REINFORCED CONCRETE AFTER ONE YEAR UNDER SUSTAINED LOADING

Test values are given for the test specimens shown. Columns section No. 24 is the average of 4 columns.

Normal Design			Column After One Year Under Sustained Loading		Column After One Year Under Sustained Loading		Ratio P <sub>2</sub> /P <sub>1</sub>
Reinforcement No.	Percentage of Reinforcement		Ultimate Load, P <sub>1</sub>		Ultimate Load, P <sub>2</sub>		
	Vertical	Horizontal	In	Per cent of P <sub>1</sub>	P	In per cent	
LABORATORY AIR STORAGE							
2000	1.5	2	211,000	90%	244,000	4,800	0.97
	4	0	212,000	91%	244,000	4,800	1.04
	4	2	241,000	105%	244,000	4,800	0.98
	6	2	250,000	109%	244,000	4,800	1.04
2500	1.5	0	220,000	82%	244,000	4,800	0.99
	4	0	222,000	83%	244,000	4,800	0.98
	4	2	241,000	105%	244,000	4,800	0.98
	6	2	241,000	105%	244,000	4,800	0.98
3000	1.5	2	255,000	104%	244,000	4,800	1.02
	4	0	255,000	104%	244,000	4,800	1.12
	4	2	255,000	104%	244,000	4,800	0.97
	6	2	255,000	104%	244,000	4,800	1.01
Average							1.01
Mid-Height							
2000	4	0	220,000	91%	244,000	4,800	0.96
	4	1.2	222,000	91%	244,000	4,800	0.97
	4	2	241,000	105%	244,000	4,800	1.01
2500	4	0	241,000	105%	244,000	4,800	1.11
	4	1.2	241,000	105%	244,000	4,800	0.98
	4	2	241,000	105%	244,000	4,800	0.98
3000	4	0	255,000	104%	244,000	4,800	0.90
	4	1.2	255,000	104%	244,000	4,800	0.97
	4	2	255,000	104%	244,000	4,800	1.00
Average							0.98
Grand Average Value of Ratio P <sub>2</sub> /P <sub>1</sub>							1.00

\* Reproduced from Reference 1.

TABLE 2

Properties and Test Results of Laminas Subjected to Shear and  
Failing before Yielding of Longitudinal Reinforcement

Mark	$f'_c$ psi	Reinforcement				Shear Stress $v_u$ psi
		Long.		Transv.		
		$\rho_A$ %	$f_y$	$\rho_T$ %	$f_y$	
PV 9	1680	1.79	66.0	1.79	66.0	542
PV 10	2100	1.79	40.0	1.79	40.0	573
PV 12	2320	1.79	68.0	.45	39.0	454
PV 13	2640	1.79	36.0	0	0	292
PV 18	2830	1.79	62.5	.32	59.7	440
PV 19	2760	1.79	66.4	.71	43.4	573
PV 20	2840	1.79	66.7	.89	43.1	617
PV 21	2830	1.79	66.4	1.30	43.8	729
PV 22	2840	1.79	66.4	1.52	60.9	880
PV 26	3090	1.79	66.1	1.01	67.1	784
PV 27	2970	1.79	64.1	1.79	64.1	920
PV 30	2770	1.79	63.3	1.01	68.4	744

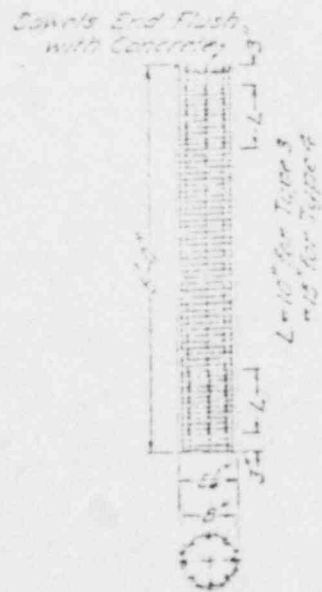
Note: Data from Reference 4.



FIGURE 1

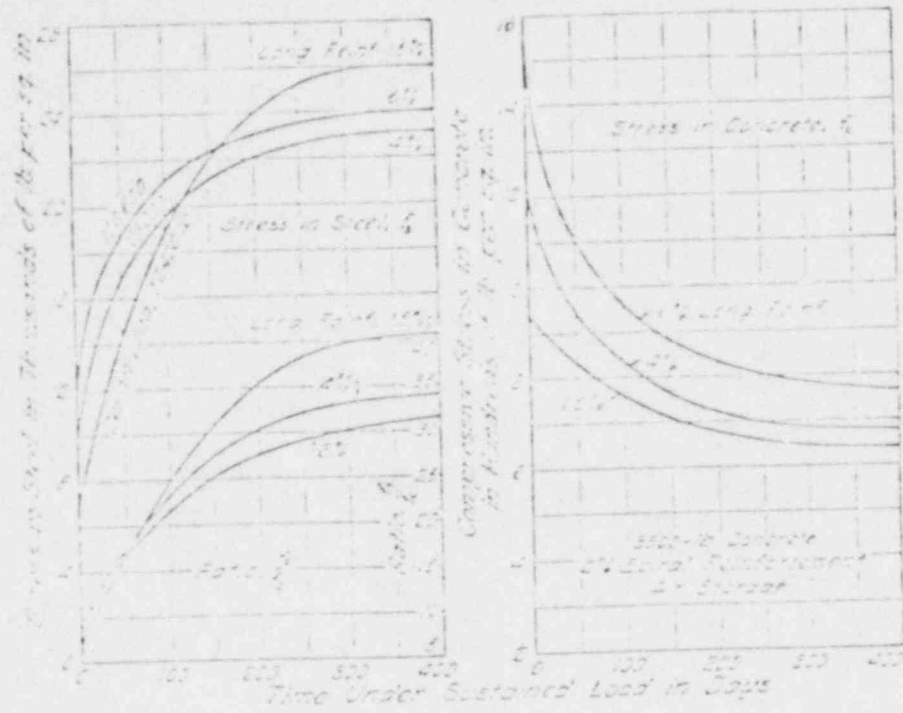


FIGURE 2



Types 3 and 4

FIGURE 3



REDISTRIBUTION OF STRESSES IN CONCRETE AND STEEL  
DURING SUSTAINED LOADING

FIGURE 4

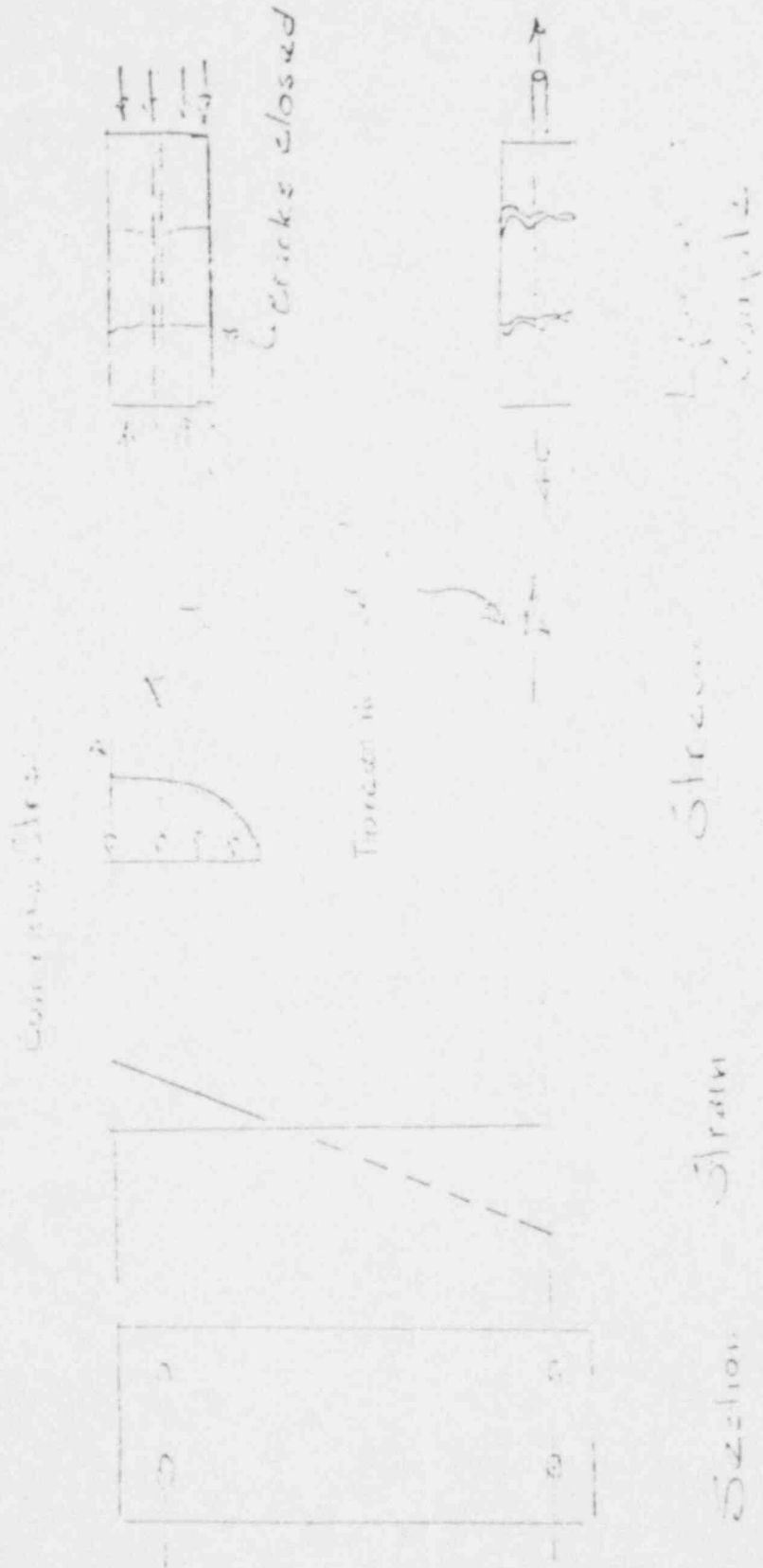
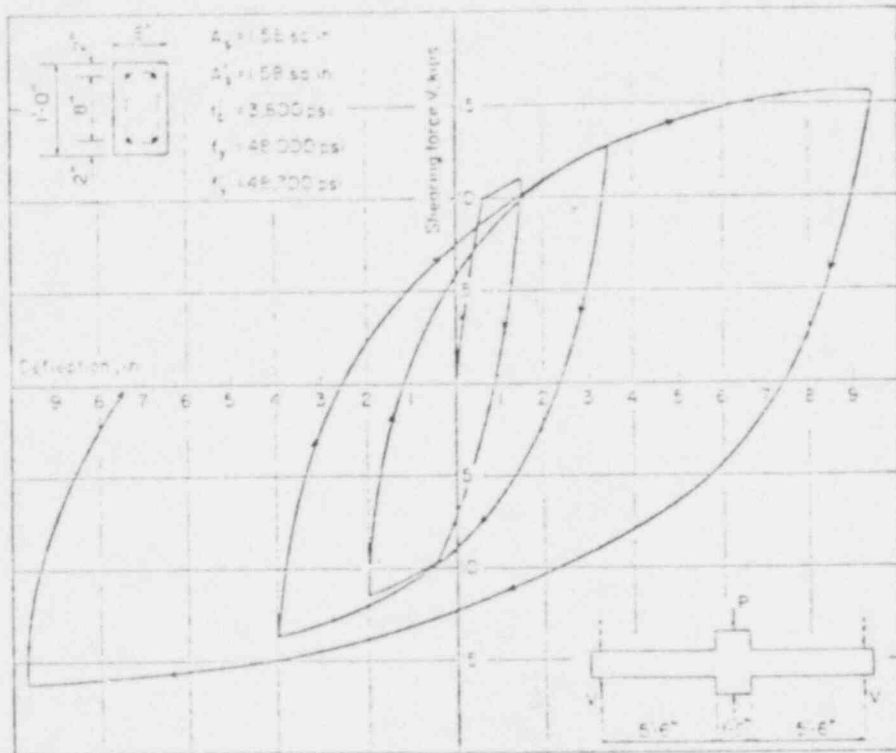


FIGURE 5



Measured load-deflection relationships for a beam-column connection subjected to reversal of load.

FIGURE 6  
(From Reference 2)

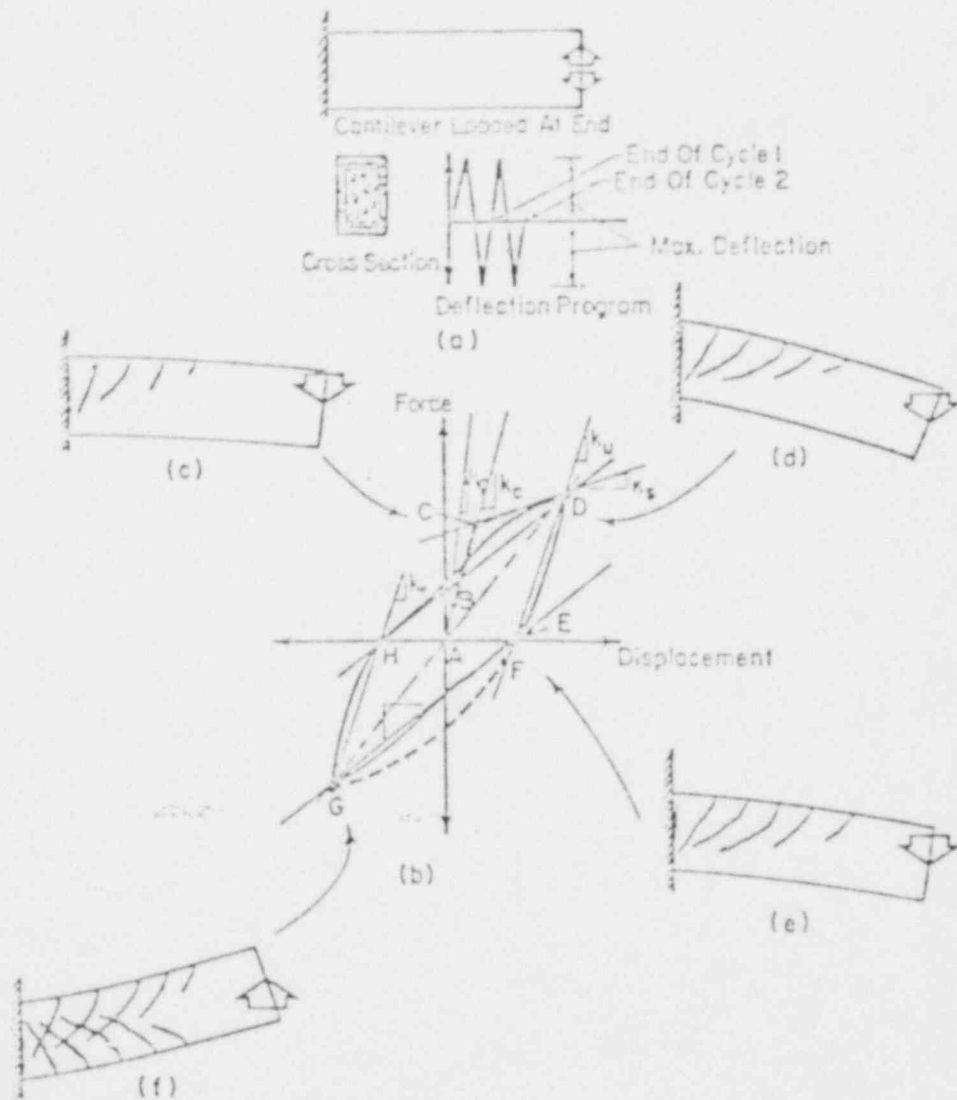


FIGURE 7.  
(From Reference 2)



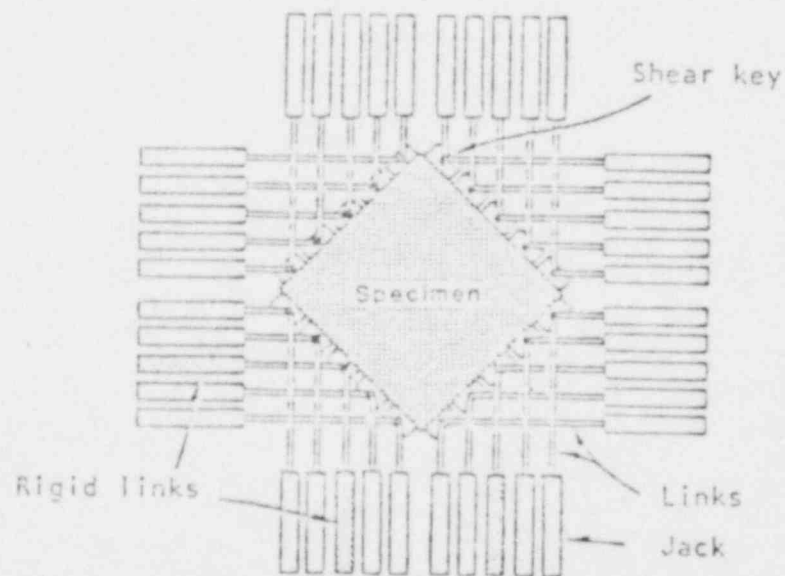
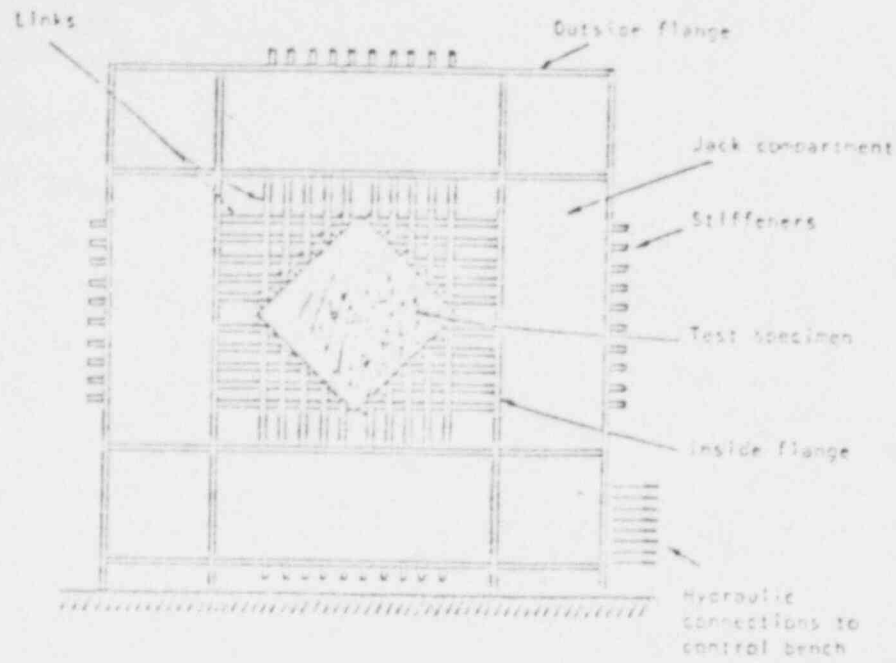


FIGURE 5

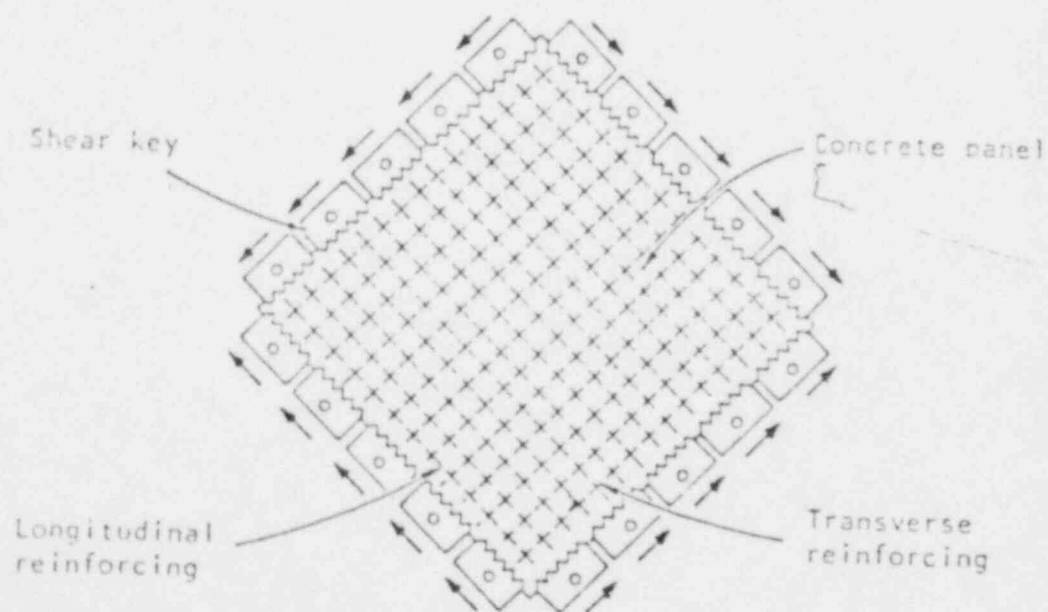
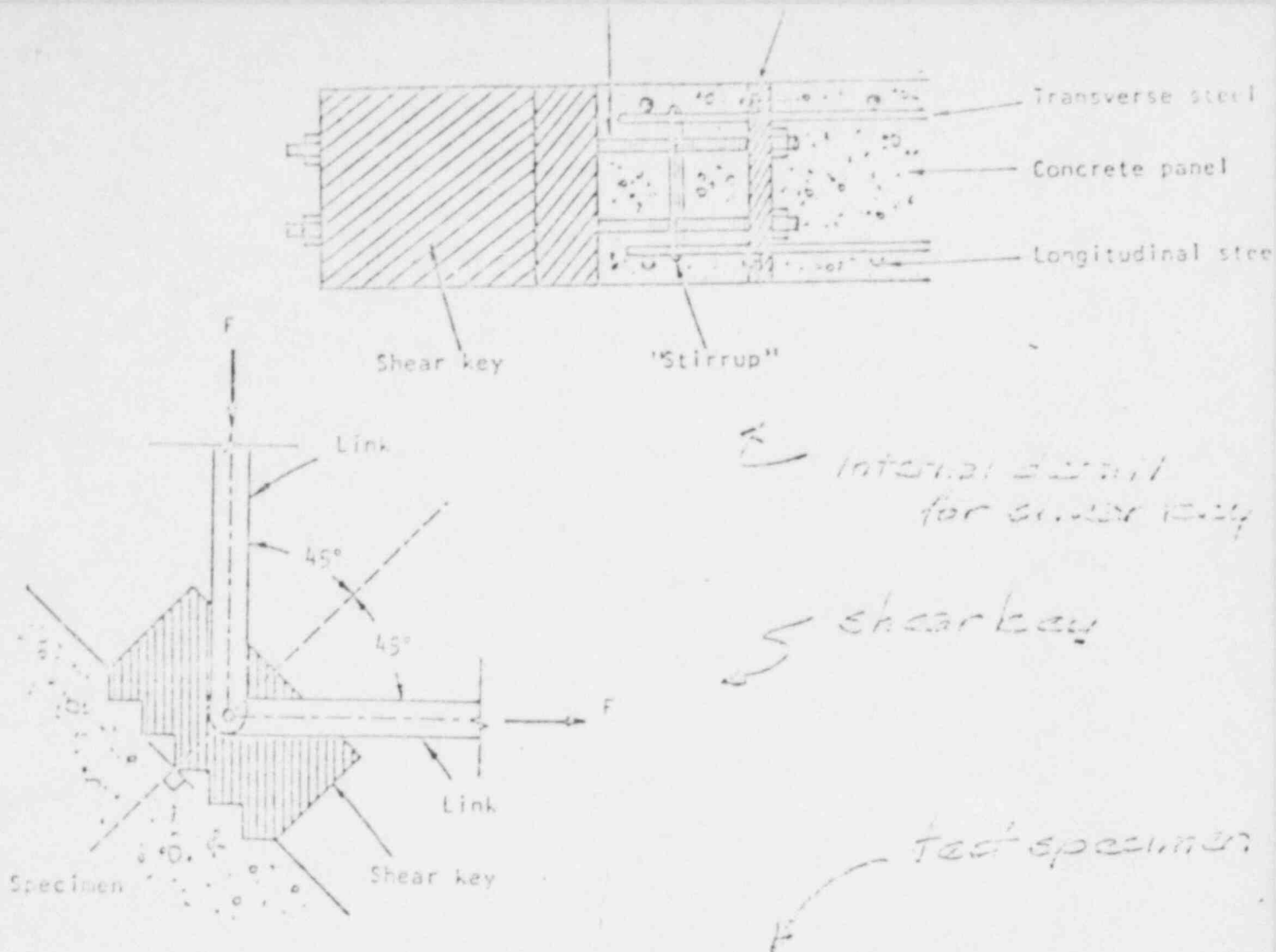
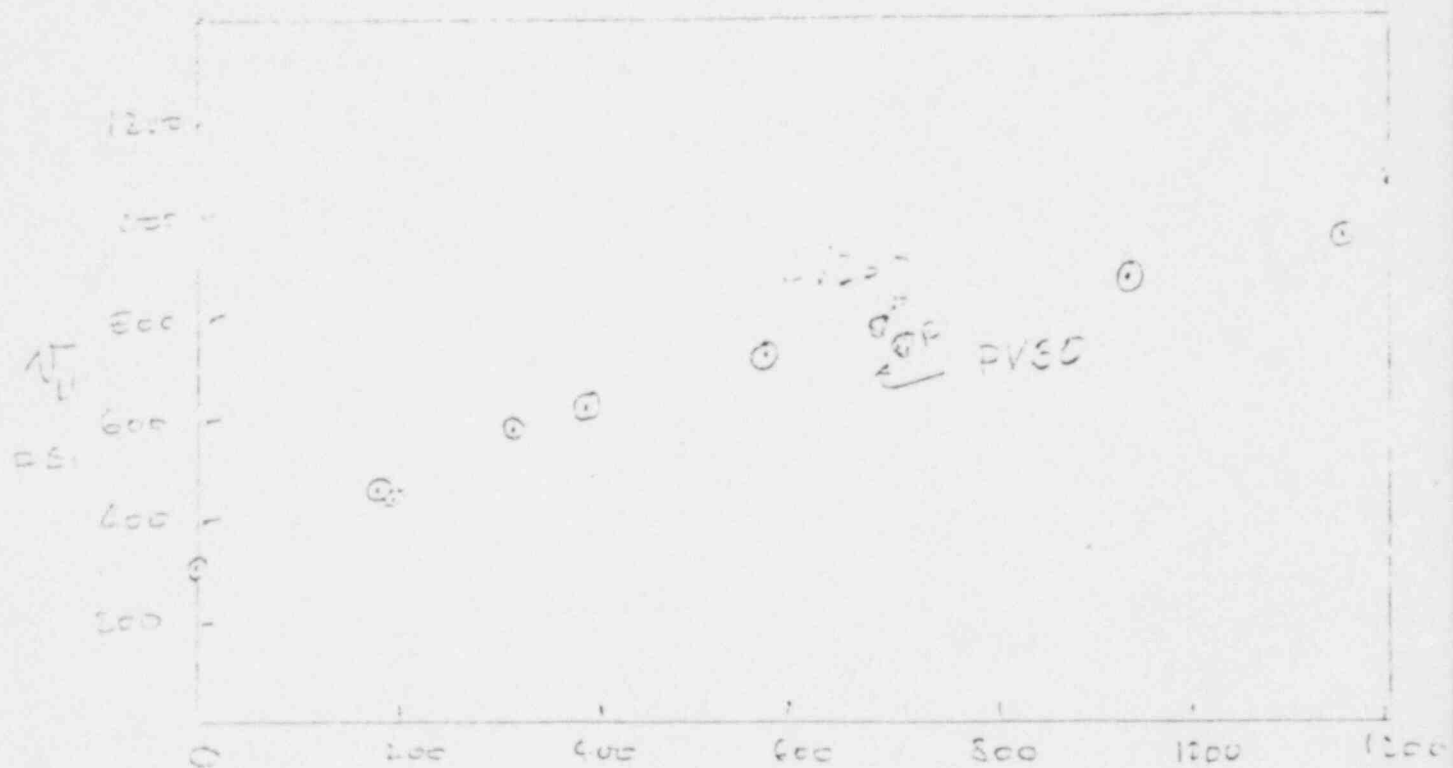


FIGURE 9



$$P = \frac{P}{f_y}, \text{ psi}$$

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FIGURE 10  
(Data from Reference 4)



MEETING SUMMARY DISTRIBUTION



Docket File 30-329-00706  
NRC/PDR  
Local PDR  
TIC/NSIC/TERA  
LB #4 r/f  
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