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REPORT OF INVESTIGATION, FIRST FLOOR SLAB
IN ORNL BUILDING 9204-1, Y-12 PLANT

Edwin G. Burdette

Y/EN--611

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REPORT OF INVESTIGATION

FIRST FLOOR SLAB IN ORNL BUILDING 9204-1

Y-12 PLANT

UNION CARBIDE CORPORATION, NUCLEAR DIVISION

OAK RIDGE, TENNESSEE

July 1981

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REPORT OF INVESTIGATION
FIRST FLOOR SLAB IN ORNL BUILDING 9204-1

by
Edwin G. Burdette

1. INTRODUCTION

A question that is raised repeatedly in structural engineering practice relates to allowable forklift truck loads on building floors. This question is a particularly important one for situations occurring in a number of reinforced concrete buildings in the Oak Ridge Y-12 Plant (a) area at Oak Ridge, Tennessee. Many of the buildings were built in the 1940's and were designed under the provisions of an American Concrete Institute (ACI) wartime building code which reduced the minimum steel requirements below those in use before the 1940's and those in use today. The use of such low steel ratios poses special problems that are discussed later herein.

Recent attention has been focused on the problem of allowable fork truck loadings in some of the ORNL buildings in the Y-12 area due to a need to use fork trucks to service various projects housed in these buildings. The use of relatively heavy fork trucks is generally crucial to the successful and efficient operation of a project; thus, it is important that a realistic assessment be made of the safe axle loads which may be carried by the floors in the buildings in question.

(a) Operated by the Union Carbide Corporation, Nuclear Division, for the Department of Energy.

1.1 Objective

The primary objective of the work reported here was to determine safe allowable axle loads for fork trucks using above grade floors in certain ORNL buildings in the Y-12 area. A necessary part of the accomplishment of this objective was the formulation of a method for assessing the flexural capacity of a slab and for determining the bending moment induced by an applied axle load.

1.2 Approach to the Problem

A decision was made to focus on a particular slab region on the first floor of Building 9204-1. This slab had one of the lowest allowable axle loads, as determined from earlier analyses, and it was located in an area where the use of 4000-lb. fork trucks loaded to capacity was crucial to the performance of the large coil fusion project. Also, it was in a location easily assessible for experimental investigation. The procedure followed to attain the desired objectives is described in the following.

- (1) Load tests on a slab in Building 9204-1 were performed. Two fork trucks, 4000 and 6000-lb. capacity, were used. The trucks were loaded to different load levels, the axle loads were obtained by weighing, and the trucks were run, singly, over the slab. This investigation is described in detail in Section 2 of this report.

- (2) Both computer (finite element) and hand analyses were made as described in Section 3.
- (3) Criteria were defined, based on the experimental and analytical studies, to determine a reasonable safe axle load (Section 4).
- (4) Finally, in Section 5, a procedure is given for extending the results to other slabs.

2. EXPERIMENTAL INVESTIGATION

Tests were performed on a portion of the first floor slab of Building 9204-1 located in an aisle used regularly by fork trucks. The location of this portion of slab was between column lines f and g and lines 27 and 30.

2.1 Description of Tests

A relatively simple test program was initiated with the dual objectives of (1) assessing the capability of the slab to support the desired fork truck loads and (2) obtaining data for comparison with results from a finite element solution. The tests consisted of driving a loaded fork truck onto the slab at a known location and measuring the deflections of the slab and beam. There were two fork trucks used, a 4000-lb. capacity truck and a 6000-lb. capacity truck. For different specified lifts, both axle loads were measured for each truck. These values are listed in Appendix A.

Two deflection measurements were made for each position of a truck for each lift; one of these was the absolute vertical deflection of the beam at a point directly beneath the line of travel of the fork truck (approximately mid-span of the beam), and the other was the deflection of the slab at mid-span, also at a location directly below the line of travel of the fork truck. The slab deflection was the deflection of the slab relative to the beams -- not the absolute deflection of the slab.

Two sets of measurements were made for each lift for each direction of the truck: (1) with the front wheels at mid-span of the slab and (2) with the rear wheels at mid-span of the slab. The truck was then driven rapidly over the slab to measure dynamic effects. This run was repeated with the truck headed in the opposite direction. A copy of the original data is shown in Appendix A.

2.1 Results

The results of the tests are shown graphically in Figures 1 and 2. The data in Figure 1 for the 6000-lb. capacity truck plot a straight line through zero which represents linearly elastic behavior. The data for the 4000-lb. truck were not so ideal but were not unreasonable. In neither case was there any evidence that the slab had begun to yield under high loads. While the data for the beam shown in Figure 2 exhibited more scatter, there was again no evidence of a reduction in stiffness of the beam at high loads. The lines on the graphs resulting from a finite element solution are discussed in Section 3.

In the process of performing the tests, a reinforcing bar was observed to be protruding from the bottom of the first floor slab in Building 9204-1 near the test area. A short length of this bar was broken off, taken to the laboratory, gaged, and tested. The resulting stress-strain curve is shown in Figure 3. The steel is specified on the plans for the building as Grade 40; the stress-strain curve more nearly resembles

that of Grade 60 steel. Also, a concrete test core, 5.63-in. long by 5.68-in. diameter, was obtained from a concrete slab on the same floor in another location. The compressive strength of this core, corrected to be consistent with a cylinder with a 2:1 length to diameter ratio, was 5,525 psi.

The results of the experimental investigation may be summarized as follows:

- (1) There was no visible evidence of any distress of the slab or beams under any of the loadings. The load-deflection curves support this observation, as there is no evidence of any non-linearity at high loads. Thus, the slab and beam system appeared to be capable of supporting the fully loaded trucks safely.
- (2) The moving load tests indicated a dynamic load factor of approximately 1.04. This factor is considerably lower than that generally used in design but was obtained consistently with the several different truck loadings. One run with the 4000-lb. truck was made with a 1-in. thick board in the path of the truck. Even with this situation, the dynamic load factor was approximately 1.05.

3. ANALYTICAL STUDY

The analytical study consisted of two parts, a finite element analysis and a hand calculation solution based on moment coefficients. The finite element analysis utilized the ICES STRUDL II plate bending capabilities with the mesh illustrated in Figure 4. The results for all elements uncracked and for the the case of cracked elements in high moment regions are plotted on Figures 1 and 2.

Calculations based on moment coefficients are included in Appendix B. These coefficients were obtained from Dunham (Reference 1), who based his values on earlier work by Westergaard (Reference 2). A modification of this work to consider flexural analysis of slabs in terms of an "effective width" is presented by Cook in Reference 3. The results of his work support the conclusions presented herein.

The results of the finite element analysis and the hand analysis with coefficients are reasonably consistent. The positive moment caused by the two front wheels of the typical 4000-lb. capacity truck used in the calculations was 0.18 P using Reference 1, 0.144 P using an uncracked section finite element solution, and 0.112 P using a finite element analysis with some sections cracked, where P is the sum of the two front wheel loads. Based on these results and the results of other calculations and comparisons (as illustrated in the first set of calculations in Appendix B), two important decisions were made:

- (1) In almost all cases the positive moment near mid-span of the slab will be the critical moment;
- (2) The magnitude of this moment is essentially independent of span length and is approximately $0.15 P$, where P is the sum of the two front wheel loads on the slab.

4. RECOMMENDED ALLOWABLE AXLE LOAD

The following criteria were used to determine a recommended allowable axle load for the first floor slab in Y-12 Building 9204-1:

- (1) The positive bending moment required to cause yield of the tensile steel in the slab was calculated for an assumed value of steel yield stress of 40 ksi. The 1-in. concrete wearing surface was assumed to act monolithically with the rest of the slab. This wearing surface was cast against roughened concrete, and the wheel loads are applied directly to the wearing surface. Thus, it is almost certain that there can be no relative lateral movement between wearing surface and the rest of the slab in the region of high positive moment.
- (2) The maximum positive moment produced in the slab by existing dead and live loads was calculated as $1/16$ of the sum of dead and live loads multiplied by the square of the clear span of the slab between beams. The dead load used in the calculation included the weight of the floor slab plus the wearing surface, and a uniform live load of 20 psf was used. The relatively low value of live load was used because any live load applied to the slab is outside the fork truck aisles and thus has minimal effect on moments.
- (3) The positive moment produced by a loaded fork truck was taken as 0.15 times the total load on the loaded axle. This value was multiplied by 1.10 to account for impact.

- (4) A factor of safety against yielding of 1.30 was chosen. The allowable axle load was then calculated by dividing the difference in the yield moment and the sum of dead and live load moments by the quantity $(0.15 \times 1.10 \times 1.30)$. These calculations led to a moment difference of 1.945 kip-ft./ft. and a corresponding value of maximum axle load of 9.07 kips (9,070 lbs.) (This calculation is shown on the first sheet of calculations in Appendix B.)

Based on the preceding criteria, a recommended allowable axle load of 9,070 lbs. is presented. The tests described in Section 2 of this report confirm the adequacy of the first floor slab to support this load with no apparent distress. In fact, based on those tests, an argument could be made that the recommended value of 9,070 lbs. is unduly conservative. However, uncertainties in slab conditions in other regions of the first floor, coupled with uncertainty about long term behavior of the slab tested when that slab is subjected to a high number of repetitions of wheel loadings, leads to a reluctance to recommend a higher allowable load than the 9,070 lbs. just noted.

5. EXTENSION OF METHOD TO OTHER SLABS

A simple procedure was devised to extend the method developed for the first floor slab of Building 9204-1 to other, similar slabs. This procedure is as follows:

- (1) The value of yield moment is calculated. The yield stress of the steel is taken as either 33 or 40 ksi for "structural grade" or "intermediate grade" steel, respectively.
- (2) The dead plus live load moment is calculated as described in Section 4, and the difference between the yield moment and this moment is calculated. The remaining moment is noted as M_r .
- (3) The allowable axle load, P, in pounds, is calculated as follows:

$$P = (9,070) \left(\frac{M_r}{1.945} \right)$$

The recommended allowable loads obtained in this manner for other slabs are consistent with the criteria presented in Section 4 herein.

6. COMMENTS, CAUTIONS, AND CONCLUSIONS

The recommended allowable axle load for the first floor slab of Building 9204-1 and the method for determining similar values for other slabs are believed to be reasonable. However, certain comments and cautions are in order.

- (1) The recommended loads obtained on the basis of this report are not to be confused with "design loads" for the slabs being considered. A designer working under the provisions of the ACI Building Code (ACI 318-77; Reference 4) would never permit an axle load of 9,070 lbs. on the first floor of Building 9204-1 or, more logically, a designer would never design such a slab to support that axle load. Instead, he/she would probably use a thicker slab, and certainly one with more steel in it, consistent with the ACI code. The slabs under consideration, however, are already built and in use; and in most cases they are performing adequately. Thus, while it is with some degree of fear and trembling that a structural engineer recommends a larger allowable load than a code would permit, it is the opinion of this writer that the recommended allowable axle loads are "safe"; but he would urge (1) that the condition of each floor slab be reviewed periodically and (2) that the precautions regarding high overloads noted in a subsequent comment herein be strictly observed.

- (2) As noted in the introduction to this report, the slabs under consideration were designed under a wartime code that permitted the use of reinforcing steel areas significantly lower than those permitted under ACI 318-77. The result of the use of such low steel areas is that the moment required to cause tensile cracking in the slab is greater than the moment required to produce yield in the tensile steel. Thus, such a slab generally remains uncracked under service loads, and the amount of reinforcing steel present has very little effect on the slab's behavior. This consideration provides some explanation of why slabs with steel areas too small to satisfy the strength provisions of the code for the applied wheel loads are able to perform satisfactorily; namely, the cracking moment capacity of the slab is large enough to maintain the slab in an uncracked condition.
- (3) In view of the situation just discussed, it is important that any slab which is presently uncracked remain uncracked. Thus, every precaution should be taken not to subject a slab to a high overload, even for a one-time application. Such an overload might crack the slab and cause it to become more flexible and, at the same time, cause higher strains to be introduced into the reinforcing steel as wheel loads are repeatedly applied. A specific example of such a high overload is the 41,000 lb. regulator in Building 9201-2 which must be moved periodically.

Movement of this regulator should be accomplished with extreme care to prevent cracking any of the slabs in the affected regions.

It should be noted that cracking of the slabs will not affect the safety factor against yielding that was used in the determination of the recommended allowable axle load. Cracking could, however, seriously affect the behavior of the slab and, over a period of time, necessitate a re-evaluation of the recommended load.

REFERENCES

1. Dunham, Clarence W., Advanced Reinforced Concrete, McGraw-Hill Book Company, New York, 1964.
2. Westergaard, H. M., "Computation of Stresses in Bridge Slabs Due to Wheel Loads," Public Roads, Vol. II, No. 1, March 1930, pp 1-23.
3. Cook, Ronald W., "A Design Guide for Evaluating the Moments in Reinforced Concrete Slabs Subjected to Concentrated Loads," Unpublished Report Submitted for Credit in C.E. 5900, The University of Tennessee, Knoxville, July 1981.
4. American Concrete Institute, Building Code Requirements For Reinforced Concrete, ACI 318-77, Detroit, Michigan, 1977.

FIG. 1. PLOT OF SLAB DEFLECTION VS. LOAD

FIG. 2. PLOT OF BEAM DEFLECTION VS. LOAD

FIG. 3. STRESS-STRAIN CURVE FOR REINFORCING BAR FROM SLAB
IN FIRST FLOOR OF BUILDING 9204-1

EGB
5/21/81

APPENDIX A

TEST DATA

FORK TRUCK DATA

6000# CAP

TRUCK NO.	DESCRIPTION OF LOAD CONDITION	TOTAL WGT, W (LBS)	FRONT AXLE, R _F (LBS)	REAR AXLE, R _R (LBS)	AXLE SPG, L (FT.)	WHEEL SPG, P (FT.)
4000# CAP.	NO LOAD	7,740			4'-1"	3'-0"
#75-9666	+ 1,000# (3'-10")		4,260	4,520		
MID #314-0196	+ 2,115#		6,400	3,660		
	+ 3,050#		7,560	3,320		
	+ 4,000#	11,920	8,700	3,180		
6000# CAP.	NO LOAD	11,240			5'-9"	4'-2"
#75-7512	+ 1,500#		8,500	4,440		
MID #3161-0276	+ 3,050#		11,320	3,100		
	+ 4,550#		12,880	3,160		
	+ 6,115#	17,600#	15,500	2,060		

SLAB TEST DATA

3/31/81

EGB

LOAD CASE	E SPAN TOTAL LOAD	DESCRIPTION OF LOAD ~ POSITION, DIRECTION, STATIC or MOVING	DIAL AT BEAM	DIAL AT E SLAB	DIAL AT 1/4 P. SLAB	DIAL AT SPAN 2
TRUCK + 1000#	4,260#	TRUCK HEADED WEST ~ CENTERED OVER DIALS ~ STATIC ~ FRONT WHEELS @ DIAL	9	12	3	
"	4,260	SAME // 1. FRONT WHEEL - REAR @ DIAL @ E SLAB SPAN 1	9	12	3 4	
	4,520	SAME / REAR WHEEL ON TAPE	4	12.5	3	
	4,260	TRUCK HEADED EAST ~ LEFT FRONT WHEEL ON TAPE - STATIC	4	12.5	3	
	4,520	SAME / LEFT BACK WHEEL ON TAPE	8.5	12	2.3	
	4,260	TRUCK HEADED NORTH / LEFT FR. WH. ON TAPE / STATIC	8	13	3	
		SAME // TRUCK CENTERED ON TAPE	6	13.5	3.5	
		TRUCK HEADED WEST / MOVING	9.5	13		$I = \frac{13.0}{12.5} = 1.04$
		MOVING EAST	9.5	13		$I = \frac{13}{12.5} = 1.04$
		MOVING WEST	9.3	13		$I = \frac{13}{12.5} = 1.04$ (AVG. I = 1.04)
		SPAN 2 - TR. WEST - RT. FR. WH. ON TAPE				
TRUCK + 2115	6,400	TRUCK HEADED WEST ~ FR. WH. ON TAPE ~ STATIC	10 9	13 13.5	ADJUSTED ZERO 3.5	
	3,660	SAME / REAR WH. ON MARK	4	9.5	2.5	
	6,400	SAME / HD EAST - LEFT FR. WH. ON MARK	6	13.9	3.5	
	3,660	SAME / REAR WH. ON MARK	11	9.1	2.5	
		HEAD EAST MOVING	11	14.0		$I = \frac{14.0}{13.9} = 1.007$
		HEAD WEST MOVING	11	14.1		$I = \frac{14.1}{13.0} = 1.085$
		" EAST "	11	14.0		$I = \frac{14}{13.1} = 1.067$
		" WEST "	11	13.8		$I = \frac{13.8}{13.0} = 1.062$ (AVG. I = 1.04)

SLAB TEST DATA

LOAD CASE	SPAN TOTAL LOAD	DESCRIPTION OF LOAD ~ POSITION, DIRECTION, STATIC or Moving	DIAL AT BEAM	DIAL AT SLAB	DIAL AT 1/4 R. SLAB	DIAL AT SPAN 2	REMARKS
TRUCK + 3,050	7,560	HEADED WEST ~ FR. WH. ON MARK ~ STATIC	10	16.9	4.1		
	3,320	SAME/ REAR WH. ON MARK	3.5	8	2		
	7,560	SAME/ HEAD EAST - LEFT FR WH ON MARK	6.5	17.1	4.1		
	3,320	SAME/ REAR WH. ON MARK	12	7.5	2.0		
		TRUCK HEADED WEST MOVING	12	18			$I = \frac{18}{16.9} = 1.065$
		TR. HEADED EAST - MOVING	12	17.9			$I = \frac{17.9}{17.1} = 1.047$
		" " WEST - "	12	17.2			$I = \frac{17.2}{16.9} = 1.018$
		" " EAST - "	12	17.5			$I = \frac{17.5}{17.1} = 1.023$ (Avg. I = 1.038)
TR. + 4,050	8,700	HEADED WEST. FR. WH. ON MARK - STATIC	11	17.8	4.1		
	3,100	SAME// REAR WH. ON MARK	4	10	2.9		
	8,700	HEAD EAST - LEFT FR WH ON MARK	7	18.1	4.5		
	3,100	SAME/ REAR WH ON MARK	13	10.0	2.6		
		TR. HEADED WEST - MOVING	13	18.0			$I = \frac{18}{17.8} = 1.01$
		" " EAST "		19.0			$I = \frac{19}{18.1} = 1.05$
		" " WEST "		18.8			$I = \frac{18.8}{17.8} = 1.06$ (Avg. I = 1.04)
		STATIC HEADED NORTH FR. AXLE OVER MARK	9	16.8	5.0		
		TR. @ SPAN 2 - WEST - FR. WH. ON MARK			-1		
		HEADED EAST - MOVING RUN OVER BOARD	13	20			$I = \frac{20.1}{18.1} = 1.05$
		REPEAT - EAST	13	19.8			

for 4000 # truck
Avg. I = 1.04

?

REPEAT - EAST

30 12" beam on mark

SLAB TEST DATA

3/31/81

EGB

LOAD CASE	SPAN TOTAL LOAD	DESCRIPTION OF LOAD ~ POSITION, DIRECTION, STATIC & MOVING	DIAL AT BEAM	DIAL AT SLAB	DIAL AT 1/4 PT. SLAB	DIAL AT SPAN 2
6000# TRUCK + 1500#	8,500	TRUCK WEST W/ RT. FR. WH. ON MARK - STATIC	11.0	15.2	3.8	
"	4,440	SAME // REAR WH. ON MARK	4.5	9.1	2.9	
	8,500	SAME ~ HEAD EAST W/ LEFT FR. WH. ON MARK	6.1	15.9	4.1	
	4,440	SAME ~ REAR WH. ON MARK	12.5	9.1	2.8	
		TR. HEADED EAST <u>MOVING</u>	13.0	15.0		$I = \frac{15.0}{15.9} = 0.94$
		TR. HEADED WEST <u>MOVING</u>	12.0	17.0		$I = \frac{17.0}{15.2} = 1.12$
TRUCK + 1500#		" " EAST "	12.5	17.0		$I = \frac{17.0}{15.9} = 1.07$ (AVG. I = 1.043)
TRUCK + 3,050#	11,320	TRUCK HD'S WEST W/ RT. FRONT WHEEL ON MARK ~ STATIC	12.0	19.5	4.0	
	3,100	SAME // REAR WH. ON MARK	3.0	7.0	2.1	
	11,320	HD EAST W/ LEFT FRONT ON MARK	8.5	20.3	4.5	
	3,100	SAME // REAR WH. ON MARK	14.5	7.0	2.0	
		HEADED EAST <u>MOVING</u>	14.5	—		
		" WEST "	14.5	22.0		$I = \frac{22}{19.5} = 1.13$
		" EAST "	15.5	20.0		$I = \frac{20}{20.3} = 0.985$ (I AVG. = 1.00)

SLAB TEST DATAEGB
3/31/31

LOAD CASE	SPAN TOTAL LOAD	DESCRIPTION OF LOAD - POSITION, DIRECTION, STATIC OR MOVING	DIAL AT BEAM	DIAL AT SLAB	DIAL AT 1/4 R. SLAB	DIAL AT SPAN 2
TRUCK 6000# Q.D. TRUCK + <u>4550#</u>	12,880	TR. HD WEST - LEFT FR. WH. ON MARK - STATIC	13.0	23.0	5.0	
	3,160	SAME/REAR WH ON MARK	3.5	7.9	2.9	
	12,880	HD. EAST W/ LEFT FR. WH. ON MARK - STATIC	9.8	24.0	5.1	
	3,160	SAME// LEFT REAR ON MARK	16.0	8.1	2.1	
		HEAD EAST MOVING	18.0	25.0		$I = \frac{25.0}{24.0} = 1.04$
		" WEST "	17.0	25.8		$I = \frac{25.8}{23.0} = 1.12$
		" EAST "	17.0	25.0		$I = \frac{25.0}{24.0} = 1.04$ (AVG $I = 1.07$)
TRUCK + 6115#	19,500	TR. HD WEST - LEFT FR. WH ON MARK	14.0	28.0	6.2	
	2,000	SAME/REAR WH ON MARK	3.0	5.8	2.8	
	19,500	HEAD EAST - LEFT FR. ON MARK - STATIC	12.0	28.2	6.8	
	2,060	SAME// LEFT REAR ON MARK	18.5	5.2	2.0	
		HEAD EAST MOVING	18.5	28.0		$I = \frac{28.0}{28.2} = 0.99$
		" WEST MOVING	18.5	28.8		$I = \frac{28.8}{28.1} = 1.02$
		" EAST "	19.5	28.9		$I = \frac{28.9}{28.2} = 1.02$
		" WEST "	19.5	27.5		$I = \frac{27.5}{28.1} = 0.98$ (AVG $I = 1.0035$)
		SPAN 2 - LEFT FR. WH. ON MARK - EAST				
		LEFT SET @ 1+000 (0.100") (JUST PAST 1)				

AVG. I FOR 6000# TRUCK = 1.04

APPENDIX B

CALCULATIONS

POSITIVE MOMENTS1. MAXIMUM POSITIVE MOMENT AT MID-SPAN [WHEEL LOADS]

DUNHAM : $M_E = \underline{0.18 P_A}$, WHERE P_A IS SUM OF 2
[EGB, 3-24-81, SH. 1 OF 2] WHEEL LOADS (AXLE LOAD) AT MID-SPAN.

COMPUTER : $M_E = \underline{0.144 P_A}$ ← UNCRACKED SLAB
[FINITE ELEMENT]

$M_E = \underline{0.112 P_A}$ ← SLAB CRACKED @ ± SPAN & @ SUPPORTS

$$\text{USE } M = 0.15 P_A \times 1.10 = \underline{0.165 P_A}$$

IMPACT → (TESTS GAVE 1.04 ±)

2. MAXIMUM POSITIVE MOMENT AT MID-SPAN ~ DEAD & LIVE LOADS

$$\underline{\text{DEAD LOAD}} : M_E^+ \cong \frac{1}{16} (0.075 \text{ K}) (9.17 - 1.33)^2 = \underline{0.283 \text{ K}}/1$$

LIVE LOAD : THE LIVE LOAD IS APPLIED OUTSIDE OF FORK TRUCK CORRIDORS ; THIS LL HAS ONLY A SMALL EFFECT ON MOMENTS IN THE CORRIDOR AREA.

ASSUME LL MOMS. IN AFFECTED AREA ARE EQUIV. TO THAT CAUSED BY A 20 PSF UNIFORM LOAD.

$$M_E^+ = \frac{20}{76} (0.288) = \underline{0.077 \text{ K}}/1$$

$$M_D + M_L = \underline{0.365 \text{ K}}/1$$

3. MOMENT CAPACITY OF SLAB (EGB, 3-24-81, SH. 2 & 3)

$$\text{FOR } f_y = 40 \text{ ksi, } M_y = \underline{2.31 \text{ K}}/1$$

4. ALLOWABLE AXLE LOAD

$$M_y - (M_D + M_L) = 2.31 - 0.365 = \underline{1.945 \text{ K}}/1$$

$$0.165 P_A = \frac{1.945}{1.30} \quad \text{FACTOR OF SAFETY AGAINST YIELDING}$$

$$P_A = \underline{9.07 \text{ K}} > 8.70 \text{ K FROM 4000-LB TRUCK}$$

∴ FULLY LOADED 4000-LB. TRUCK IS O.K.

6000-LB. TRUCK IS 85% ± AS SEVERE AS 4000-LB; ∴ $P_A = \underline{10.67 \text{ K}}$

CAN LOAD 6000-LB. TRUCK TO APPROX 2800 ±.

NEGATIVE MOMENTS

1. MAXIMUM NEGATIVE MOMENT DUE TO WHEEL LOADS

MAX. NEG. MOM. CALCULATED FROM EMPIRICAL METHODS (DUNHAM, AASHTO) DEPENDS ON WHETHER LOAD IS @ $\frac{1}{2}$ SPAN OR @ $\frac{1}{4}$ -PT. DUNHAM GIVES BIGGER MOMENT @ $\frac{1}{4}$ -PT. BECAUSE OF REDUCED EFFECTIVE WIDTH.
FINITE ELEMENT RESULTS SHOW HIGHER MOMENTS @ $\frac{1}{2}$ w/ LOAD @ $\frac{1}{2}$:

$$M^- = 0.1136 P_A \leftarrow \text{UNCRAKED SLAB}$$

$$M^- = 0.0604 P_A \leftarrow \text{CRACKED SLAB}$$

$$\text{USE } M^- = 0.114 P_A \times 1.10 = 0.125 P_A \quad (\text{IMPACT})$$

2. M^- DUE TO DL+LL (EGB, 3-25-81)

$$M_D \approx \frac{1}{11} (0.075) (9.17 - 1.33)^2 = 0.419 \text{ k/ft}$$

$$M_L = \frac{20}{75} (0.419) = 0.112$$

$$M_D + M_L = 0.531 \text{ k/ft}$$

3. MOMENT CAPACITY OF SLAB (EGB, 3-25-81)

$$\text{FOR } f_y = 40 \text{ ksi, } M_y = 2.098 \text{ k/ft}$$

4. ALLOWABLE AXLE LOAD

$$M_y - (M_D + M_L) = 2.098 - 0.531 = 1.567 \text{ k/ft}$$

$$0.125 P_A = \frac{1.567}{1.25} \text{ F.S.}$$

$$P_A = 10.0 \text{ K} > 9.07 \text{ K FROM LAST SHEET.}$$

∴ POSITIVE MOMENT CONTROLS.

CALCULATION OF EQUIVALENT THICKNESS
FOR A CRACKED SECTION

Pos. Mom.

$$12 k d \left(\frac{k d}{2} \right) - (0.924)(5.06 - k d) = 0$$

$$6 k^2 d^2 - 4.675 + 0.924 k d = 0$$

$$6 k^2 d^2 + 0.924 k d - 4.675 = 0$$

$$k d = \frac{-0.924 \pm \sqrt{(0.924)^2 - 4(6)(-4.675)}}{12}$$

$k d = 0.809"$

INCLUDE STL. IN TOP OF SLAB:

$$n A_s = (7)(0.165) = 1.155 \text{ in}^2$$

$$12 k d \left(\frac{k d}{2} \right) - (1.155)(1.938 - k d) - (0.924)(5.06 - k d) = 0$$

$$6 k^2 d^2 - 2.238 + 1.155 k d - 4.675 + 0.924 k d = 0$$

$$6 k^2 d^2 + 2.079 k d - 6.913 = 0$$

$$k d = \frac{-2.079 \pm \sqrt{(2.079)^2 - (4)(6)(-6.913)}}{12}$$

$k d = 0.914"$

$$I = (12)(0.914)^3 / 12 + (1.155)(1.938 - 0.914)^2 + (0.924)(5.06 - 0.914)^2$$

$$I = 3.054 + 1.211 + 15.88$$

$I = 20.148 \text{ in}^4$

FOR SOLID SLAB, $I = (12)(h^3) / 12 = 20.148$

$h = 2.72"$

EGD

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NEG. MOM.

$$12(kd)^2/2 - (1.155)(4.06 - kd) - 0.924(0.938 - kd) = 0$$

$$6kd^2 - 4.689 + 1.155kd - 0.867 + 0.924kd = 0$$

$$6kd^2 + 2.079kd - 5.556 = 0$$

$$kd = \frac{-2.079 \pm \sqrt{(2.079)^2 - 4(6)(-5.556)}}{12}$$

$$kd = \underline{\underline{0.8045''}}$$

$$I = (12)(0.8045)^3/3 + (1.155)(4.06 - 0.8045)^2 + (0.924)(0.938 - 0.8045)^2$$

$$I = 2.083 + 12.24 + 0.016$$

$$I = \underline{\underline{14.34 \text{ In}^4}}$$

$$h^3 = 14.34 ; \underline{\underline{h = 2.43''}}$$

CALCULATION OF MOMENTS (REF.: DUNHAM) | OF 2

$$L = 9' - 2" = \underline{9.17'} \quad C \approx 15" = \underline{1.25'} \quad \frac{C}{L} = \underline{0.136}$$

CONSIDER A SINGLE LOAD (FIG. 6-22) $\frac{L}{\bar{L}} = \frac{9.17}{0.5} = \underline{18.33}$

SIMPLY SUPP.: $\frac{M_x}{P} = 0.29$; FIXED: $\frac{M_x}{P} = 0.22$

USE $\frac{M_x}{P} = \underline{0.255}$

EFFECT OF ADJACENT LOADS (FIG. 6-25) $\frac{y}{L} = \frac{2.833}{9.17}$

SIM. SUPP.: $\frac{M_x}{P} = 0.135$; FIXED: $\frac{M_x}{P} = 0.07$ $\frac{y}{L} = 0.309L$

USE $\frac{M_x}{P} = \underline{0.103}$

FOR EQUAL WHEEL LOADS, P:

$$M_x = 0.255P + 0.103P = \underline{0.358P}, \text{ SAY } \underline{0.36P}$$

PER FOOT OF WIDTH $\left\{ \begin{array}{l} \text{LET } W = 2P = \text{AXLE LOAD} \\ M_x = 0.36\left(\frac{W}{2}\right) = \underline{0.18W} \end{array} \right.$

CALCULATE POS. YIELD MOMENT

FROM EARLIER CALCS, $k_d = 0.914" \quad \phi I = 20.148 \text{ in}^4$ (EG8, 3/24/81, 2 SHEETS)

$$M_y = \frac{f_y}{n} \frac{I}{c} = \frac{f_y}{7} \left(\frac{20.148}{5.06 - 0.914} \right) = 0.694 f_y \times \frac{1}{2} = \underline{0.05785 f_y}$$

f_y	M_y
33	1.91 k/ft
40	2.31 k/ft
50	2.89 k/ft

CHECK M_n w/ $f_y = 40$

ASSUME TOP STL. YIELDS.

$$T = (40)(0.132) + (40)(0.165) = 11.88 \text{ k}$$

$$a = \frac{11.88}{0.85 \times 5 \times 12} = 0.233" \quad c = 0.29"$$

$$M_n = \frac{1}{2} \left[(5.28)(5.06 - \frac{0.233}{2}) + (6.6)(1.938 - \frac{0.233}{2}) \right] \quad \phi_s = \frac{1.938 - 0.29}{0.29} (0.003) = 0.017$$

$$M_n = \underline{3.18 \text{ k/ft}} > M_y, \text{ O.K.}$$

$f_s = f_y$ IN TENS.

CALCULATE WGT. OF FORK TRUCK TO CAUSE YIELD. EGB

3-24-81

2 OF 2

$$WGT. = W = 2P$$

$$M^+ = 0.36P = \underline{0.18W}$$

$$0.18W = M_y - M_{WORKING\ LOAD}^+$$

$$M_{WORKING\ LOAD}^+ \approx \frac{1}{16}(0.075)(9.17 - 1.33)^2 = \underline{0.288\frac{1}{1}}$$

$$0.18W = M_y - 0.288$$

$F_y (ksi)$	$M_y (K\frac{1}{1})$	$M_y - 0.288$	$W (LBS) \leftarrow$ (TO CAUSE YIELD)
33	1.91	1.622	9,000 (10,600#)
40	2.31	2.022	11,200 (13,200#)
50	2.89	2.602	14,450 (17,000#)

↑
 (TOTAL FORK WGT. IF 85% IS ON DRIVE AXLES)

NOTE: W IS THE SUM OF THE TWO WHEEL LOADS @ $\frac{1}{2}$ SPAN.

ALTERNATIVE APPROACH (ULTRA-CONSERVATIVE)

CONSIDER BOTH WHEEL LOADS CONTRIBUTING EQUALLY TO MOMENT @ MID-SPAN w/ NO REDUCTION FOR LONG. DISTR.

$$M = 0.28P + 0.28P = 0.56P ; \text{ OR } \underline{M = 0.28W}$$

F_y	$M_y - 0.288$	$W (LBS)$	
33	1.622	5,800	(6,800#)
40	2.022	7,200	(8,500#)
50	2.602	9,300	(10,900#)

} WORST CASE

NEGATIVE MOMS. DUE TO CONC. LOADS

AASHTO

$$S = \text{CLR. SPAN} + t_s = 9'-2" - 1'-4" + 6" = \underline{8'-4"}$$

$$E = 4 + 0.06S = 4.5'$$

$$d_e = 2E - \left(\frac{4.5}{2} - \frac{2.83}{2} \right) (2) = (9.0 - 1.67) = \underline{7.33'}$$

$$\text{USE MAX. NEG. MOM.} = 0.083 P (8.33) = \underline{0.69 P}$$

MOM. IN KIP-FT. / FT. :

$$M = \frac{0.69 P}{7.33} = \underline{\underline{0.094 P}}$$

ALT. APPROACH (CONSERVATIVE) :

$$\left(\frac{0.5P}{4.5} + \frac{0.5P}{4.5} \right) (0.69) = \underline{\underline{0.153 P}} \quad \text{(THIS EXISTS OVER A WIDTH EQUAL TO 1.67')}$$

$$\underline{\underline{\text{USE } M = 0.10 P}}$$

DUNHAM

ART-6-15, PG. 291 →

 EGB
 3-23-81
 2 OF 2

1 LOAD : $b_e = 2c + 1.4d$ or $2t + 1.4d$, WHICHEVER IS GREATER
 $c = 1.25'$, $t = 0.5'$

$$\text{USE } b_e = (2)(1.25) + (1.4)\left(\frac{7.83}{2}\right) = 2.50 + 5.48$$

1 LOAD → $b_e = \underline{7.98'}$

$$M = 0.69P \left(\frac{0.5}{7.98} + \frac{0.5}{7.98} \right)$$

$$\underline{M = 0.0865P}$$

CALCULATION OF TOTAL LOAD, P, TO CAUSE YIELD.

FROM CALCS BY EGB, 3-24-81, 2 SHEETS,
 FOR NEG. MOM., $I = 14.34 \text{ in}^4/\text{ft}$

$$M_y = \frac{f_y}{n} \frac{I}{c} = \left(\frac{f_y}{7} \right) \left(\frac{14.34}{4.06 - 0.805} \right) = 0.6294 f_y \times \frac{1}{12}$$

$$M_y = 0.0524 f_y$$

f_y (ksi)	M_y (K/ft)
33	1.731
40	2.098
50	2.620

$$\text{WEIGHT} = W = P$$

$$M \approx 0.10P = 0.10W$$

$$0.10W = M_y - M_{\text{WORKG LOAD}}$$

$$M_{\text{WORKG LOAD}} = \frac{1}{11} (0.075) (9.17 - 1.33)^2 = \underline{0.419 \text{ K/ft}}$$

$$0.10W = M_y - 0.419$$

f_y	M_y	$M_y - 0.419$	W (LBS) ← (TO CAUSE YIELD)
33	1.731	1.312	13,100
40	2.098	1.679	16,800
50	2.620	2.201	22,000

Distribution

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