DETERMINATION OF EQUIVALENT UNIFORM LIVE LOAD "ENVELOPES" FOR THE SIMPLIFICATION OF METHODS USED IN THE DESIGN OF HIGHWAY BRIDGES

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A THESIS

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DETERMINATION OF EQUIVALENT UNIFORM LIVE LOAD "ENVELOPES"

FOR THE

SIMPLIFICATION OF METHODS USED IN THE DESIGN OF HIGHWAY

BRIDGES

Approved: ______________________

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THE FOLLOWING KEY SHALL APPLY TO ALL FIGURES INCLUDED IN THIS PAPER.

Curve Number	
I.	Four lanes; lane width, thirteen feet.
II.	Four lanes; lane width, twelve feet
III.	Four lanes; lane width, eleven feet.
IV.	Four lanes; lane width, ten feet.
V.	Three lanes; lane width, thirteen feet.
VI.	Three lanes; lane width, twelve feet.
VII.	Three lanes; lane width, eleven feet.
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INTRODUCTION

The purpose of this paper is twofold. One will be the advocacy of a new safe loading to be used in the design of highway bridges. The rapid evolution of highway trucks, with trailers and semitrailers attached, have made the present American Association of State Highway Officials standards, in a sense, obsolete. That the present design loadings are inconsistent with actual vehicle loads is recognized by many. (1) They serve our present heavy vehicles by virtue of the safety margin provided in the allowable stresses; but both the loads on, and the stresses in, the bridges differ materially from those contemplated in design.

The present design loadings are inadequate for several reasons:

1. There are discrepancies between the H-S trucks and the actual vehicles.

2. In the development of equivalent uniform loads, only one H-S truck, followed by much lighter vehicle loads, is used on loaded lengths to one hundred and fifty feet.

3. It is necessary to apply both a truck concentration and the lane loadings to obtain maximum stresses.

Correction of these three inadequacies would mean the development of a new loading standard. To alleviate the discrepancies between H-S trucks and actual vehicles, a new truck loading, to be known hereafter as H32-S35 (See Appendix), has been introduced. The loading represents an actual doubleaxled trucks load as found on our highways today.(2)

To design a span for one heavy truck is impractical from the viewpoint of safety. It is not abnormal for the approaches to such municipalities as New York, Chicago, etc., to have lines of heavy trailer trucks, back to back. However, if there can be more than one vehicle or vehicle combinations on a single lane at a time, then the question arises: What is a reasonable number of maximum weight loads to assume on the span at the same time in exactly the critical position? Engineers are faced with the necessity of establishing some reasonable maximum condition as a basis for design. In developing the criteria used in this paper, three new classes of bridges have been established.(See Appendix) The loadings used on these bridges, including the type of trucks, number of trucks, and truck spacing, are based entirely on common sense.

The second purpose of this paper will be the simplification of criteria used in the design of highway bridges. At present, a uniform load plus a concentration are used, causing a multiplication of calculations. This paper advocates the use of a heavier uniform unit load to replace both the uniform lane loads and the concentrated loads used in the design of bridges today. Instead of a single uniform load, a series of live load envelopes which vary with span length, number of lanes, and lane widths, have been developed.

In developing these envelopes, which are to be used, both for simple and continuous spans, I have used twelve conditions for each class of bridges.

These conditions include;

1. Two lane bridges; width of lanes varying,(ten, eleven, twelve, thirteen feet).
2. Three lane bridges;width of lanes varying,(ten, eleven, twelve, thirteen feet).
3. Four lane bridges; width of lanes varying,(ten, eleven, twelve, thirteen feet).

For simple spans, I have developed both the figures for the maximum moments and maximum shears to be used in design, and the equivalent uniform live loads used in calculating these, aforementioned, moments and shears. By maximum design moments and shears, I refer to the actual maximum moments in the case of two lane bridges, ninety per cent in the case of three lane bridges, and seventy-five per cent of actual maximum moments in the case of four lane bridges. (3)

The tables of design moments and shears for all the classes of bridges were developed using the actual wheel concentrations placed to produce maximum conditions on the main girders.

The significance of the tables and figures for the various bridge classes will be explained in the following chapters.

CHAPTER I

The results of design calculations for maximum moments and shears for bridges in Class One, give justification to the statement that the H20-S16 loadings are inadequate. Using the H32-S35 truck, as proposed by this paper, the maximum moments have been found to be, approximately, double those achieved by the H20-S16 loadings (See Appendix).

Table I shows the actual design moments and shears for Class One bridges, for each of the twelve design conditions, at twenty foot intervals of span length. Figures 1 and 2 show the design moments and shear curves plotted from Table I. These curves may be used to find the design moments and shears for any simple span, without calculations.

Figure 1 indicates that the moments increase at an increasing rate. This is logical due to the fact that as the span length increases, the total load on the bridge, also increases. However, the design shears, Figure 2, show that as the span length increases the shear increases, but at a decreasing rate. This type of curve is explained by the fact that, as specified for Class One bridges, only two H32-S35 trucks are used. This explains the apparent straight line shear curve from forty to, approximately, one hundred and forty feet. From this point, additional, but lighter H20-S16 trucks are used, thereby, introducing a flattening of the shear curve.

Table II shows the equivalent uniform live load required to produce the same maximum moments and shears as the actual wheel loads.

TABLE I.

DESIGN MOMENTS AND SHEARS FOR CLASS I BRIDGES

Span Length	Moment* Shear	Two Lanes 10Ft.	11Ft.	12Ft.	13Ft.	Three Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	632	661	684	706	854	880	900	918
	V	80	84	87	90	108	112	115	117
60 Ft.	M	1140	1192	1235	1274	1540	1589	1624	1658
	V	106	111	115	118	143	147	152	155
80 Ft.	M	2200	2300	2380	2460	2980	3060	3130	3200
	V	141	147	153	158	190	197	202	206
100 Ft.	M	3360	3510	3640	3750	4540	4680	4780	4890
	V	156	163	169	174	210	218	224	228
120 Ft.	M	4654	4860	5030	5200	6280	6480	6630	6750
	V	174	182	188	194	234	243	249	254
140 Ft.	M	5994	6260	6480	6690	8090	8340	8540	8700
	V	188	196	203	209	253	262	269	274
160 Ft.	M	8110	8490	8770	9060	10950	11300	11550	11780
	V	227	237	246	253	305	316	325	331
180 Ft.	M	10200	10670	11050	11400	13780	14200	14520	14800
	V	246	257	266	275	331	343	353	359
200 Ft.	M	12250	12800	13250	13680	16520	17050	17420	17800
	V	262	274	284	292	352	365	375	382
220 Ft.	M	14300	14960	15500	16000	19350	19920	20400	20800
	V	275	287	297	307	370	385	394	401
240 Ft.	M	16400	17150	17750	18300	22150	22800	23350	23800
	V	286	299	310	319	386	399	410	417
260 Ft.	M	18500	19350	20000	20700	25000	25750	26300	26900
	V	295	308	319	329	395	411	423	430
280 Ft.	M	20500	21000	21700	22450	27100	27950	28600	29200
	V	303	316	328	338	407	423	434	442
300 Ft.	M	22600	23600	24500	25200	30500	31500	32200	32800
	V	310	324	335	346	416	432	444	452

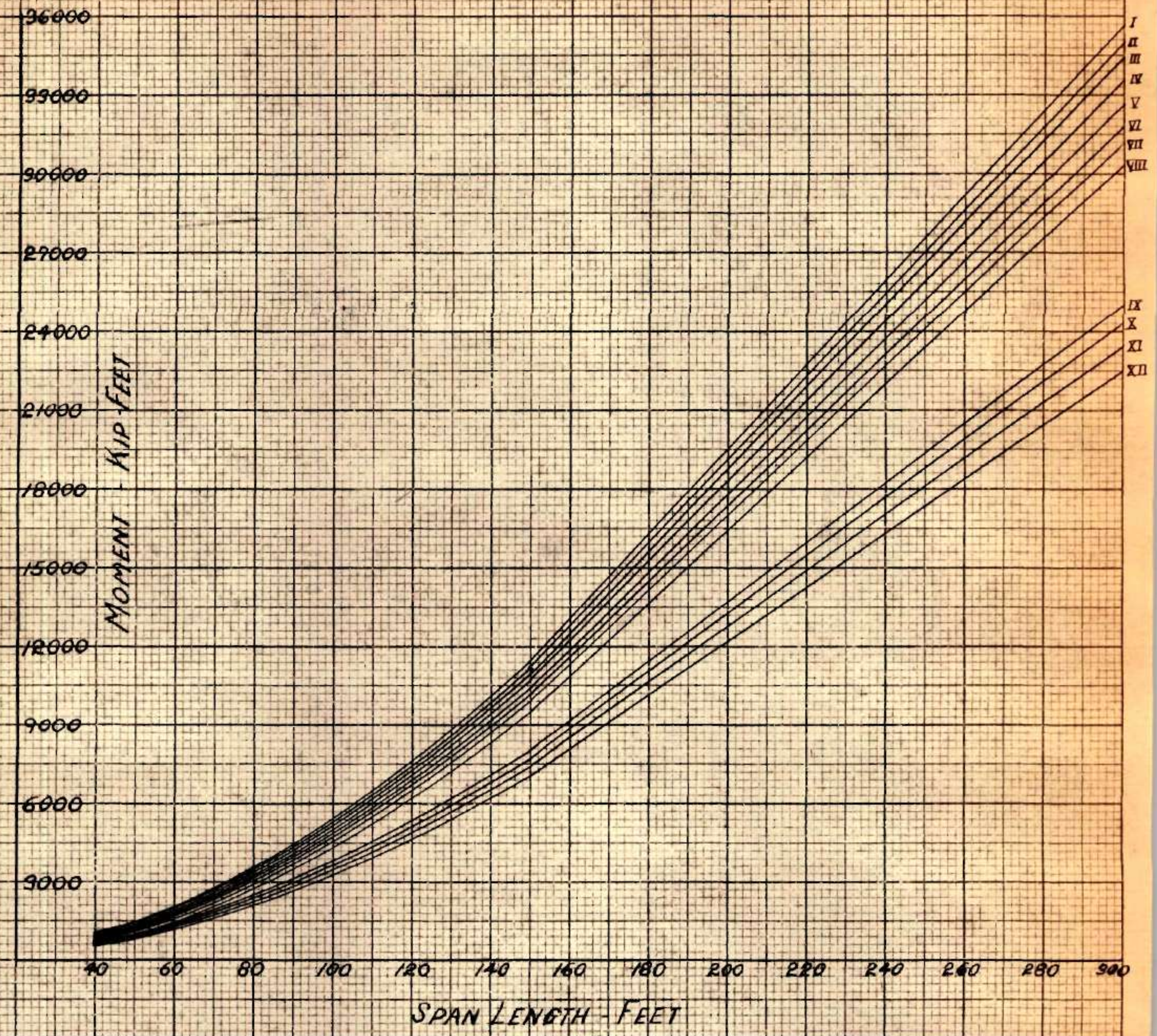
* All moments in kip-feet units.

All shears in kip units.

TABLE I. (continued)

DESIGN MOMENTS AND SHEARS FOR CLASS I BRIDGES

Span Length	Moment Shear	Four Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	949	971	990	1005
	V	120	124	126	128
60 Ft.	M	1712	1752	1788	1814
	V	159	164	166	169
80 Ft.	M	3300	3380	3450	3500
	V	211	218	222	225
100 Ft.	M	5040	5160	5260	5350
	V	234	241	245	249
120 Ft.	M	6990	7150	7280	7400
	V	260	269	273	278
140 Ft.	M	9000	9200	9390	9540
	V	281	290	295	299
160 Ft.	M	12180	12450	12700	12900
	V	339	351	356	362
180 Ft.	M	15300	15680	15950	16200
	V	368	380	387	393
200 Ft.	M	18380	18800	19180	19500
	V	392	405	411	418
220 Ft.	M	21500	22000	22400	22750
	V	411	425	432	438
240 Ft.	M	24600	25200	25700	26100
	V	428	443	449	457
260 Ft.	M	27800	28400	29000	29400
	V	441	456	463	471
280 Ft.	M	30150	30850	31450	32000
	V	453	468	476	484
300 Ft.	M	33900	34700	35400	35900
	V	463	479	486	494



"FIG. I"
DESIGN MOMENTS
CLASS I BRIDGES

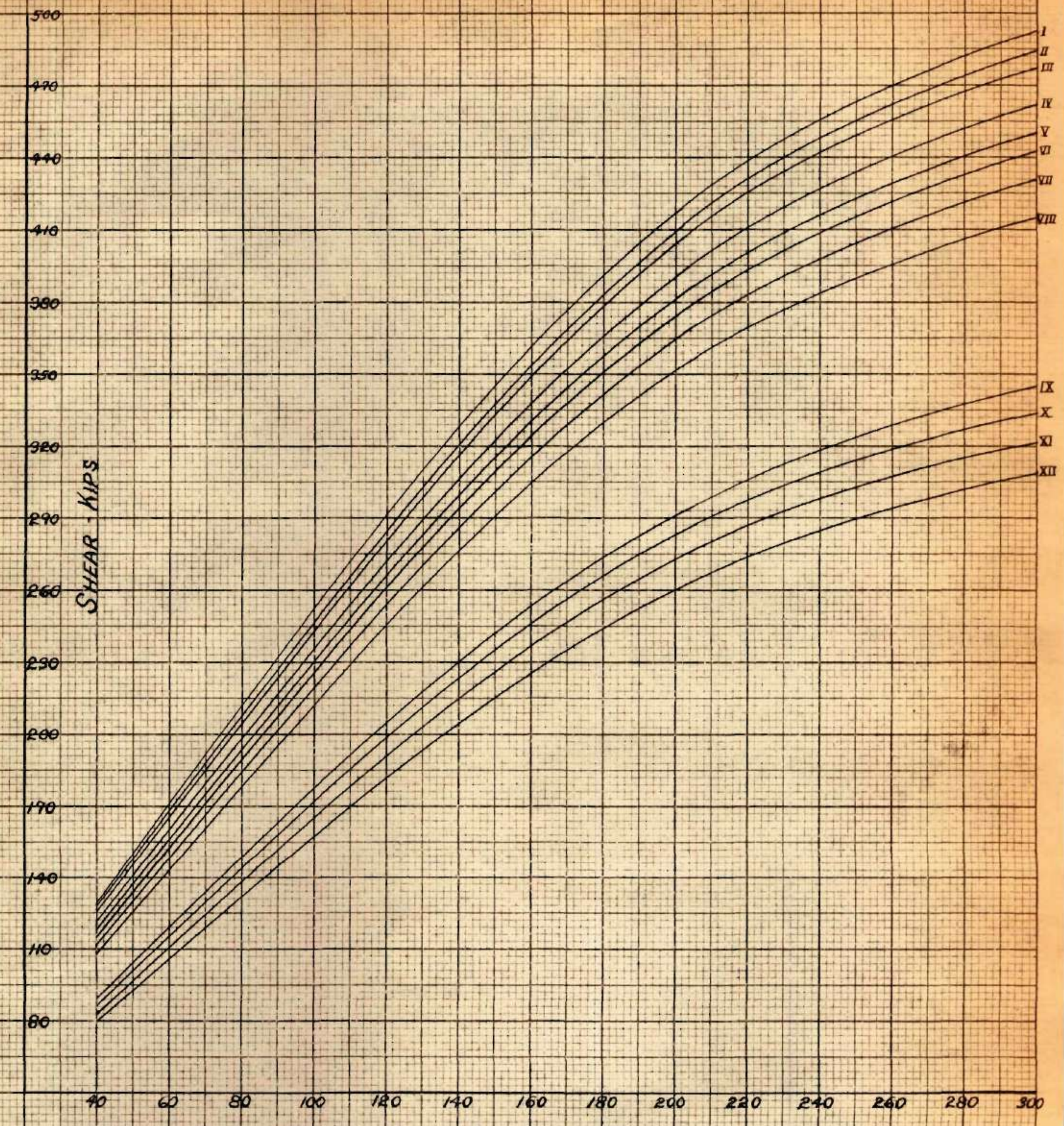


FIG. 2
DESIGN SHEARS
CLASS I BRIDGES

Figures 3 and 4 are the equivalent uniform live load envelopes for the bridges in Class One. Both figures show two decided peculiarities. The first is the break in the curves at a span length of one hundred and forty feet. This again is attributed to the break in continuity of load due to the addition of the lighter H20-S16 trucks. The second peculiarity is the fact that the equivalent uniform load for a two lane (thirteen foot lane width) bridge is less than the equivalent uniform load for a three lane (ten foot lane width) bridge. This phenomenon is explained in the following way. Both conditions have approximately the same area over which to distribute their load, however, the three lane bridge has a greater load, and therefore, the greater equivalent unit load.

The results found in the development of the figures for moment and shear for bridges designed for actual vehicle loads, (loadings commonly found on bridges that fall within this category), show a decided discrepancy between the H-S trucks and actual vehicles.[1] It is therefore believed that this class of loading will serve as a corrective measure for the first inadequacy of the present system, mentioned presiously.

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[1] How large a discrepancy actually exists may be noted by investigating the design calculations found in the appendix.

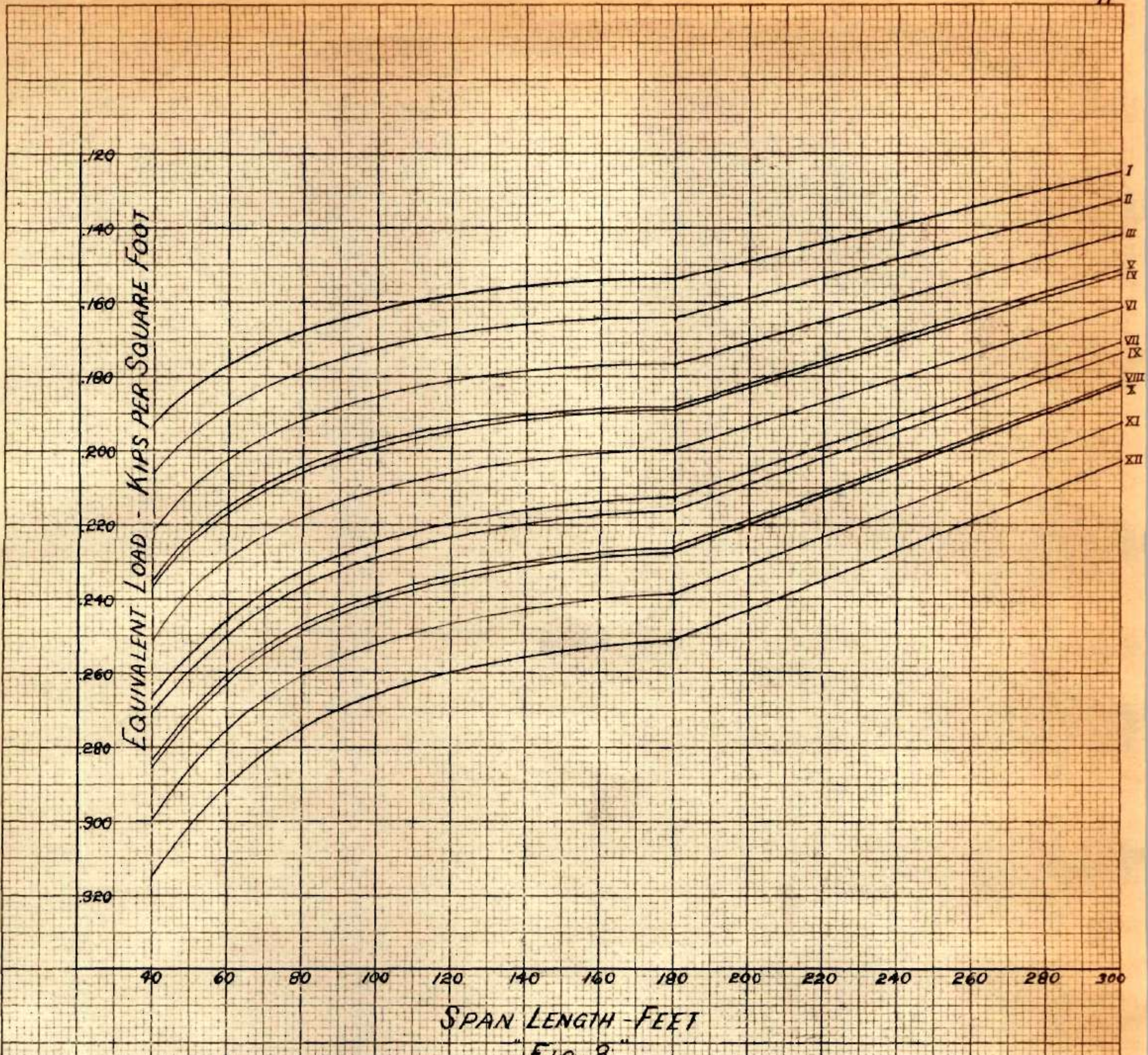
CHAPTER II

There is very little difference in the bridges that fall within Class II as proposed by this paper and the H20-S16 class used in the design of most bridges today. The one difference, the addition of more than one H20-S16 truck, is of vital importance. The amount of truck traffic on our inter-state highways has increased to such an extent that the design of bridges for just one heavy truck and a much lighter uniform load is, indeed, inadequate.

For short spans, the design moments, calculated by using the actual wheel loads proposed in this paper, agree very closely with those obtained by using the uniform load and con-centrated load recommended by the American Association of State Highway Officials. However, when additional truck loads are added for the longer span lengths, the design moments and shears of the actual wheel loads exceed those of the American Association of State Highway Officials by thirty to thirty-five per cent. (See appendix). This is a glaring example of the second dis-crepancy between the present loading standards and actual vehicle loads.

Table III shows the actual design moments and shears for bridges of Class II, for all twelve conditions of design. Figures 5 and 6 show the the design moments and shears for any span lengths from forty to three hundred feet.

The figures, as would be expected, have the same type of curves as those found in Class One. The explanation for the

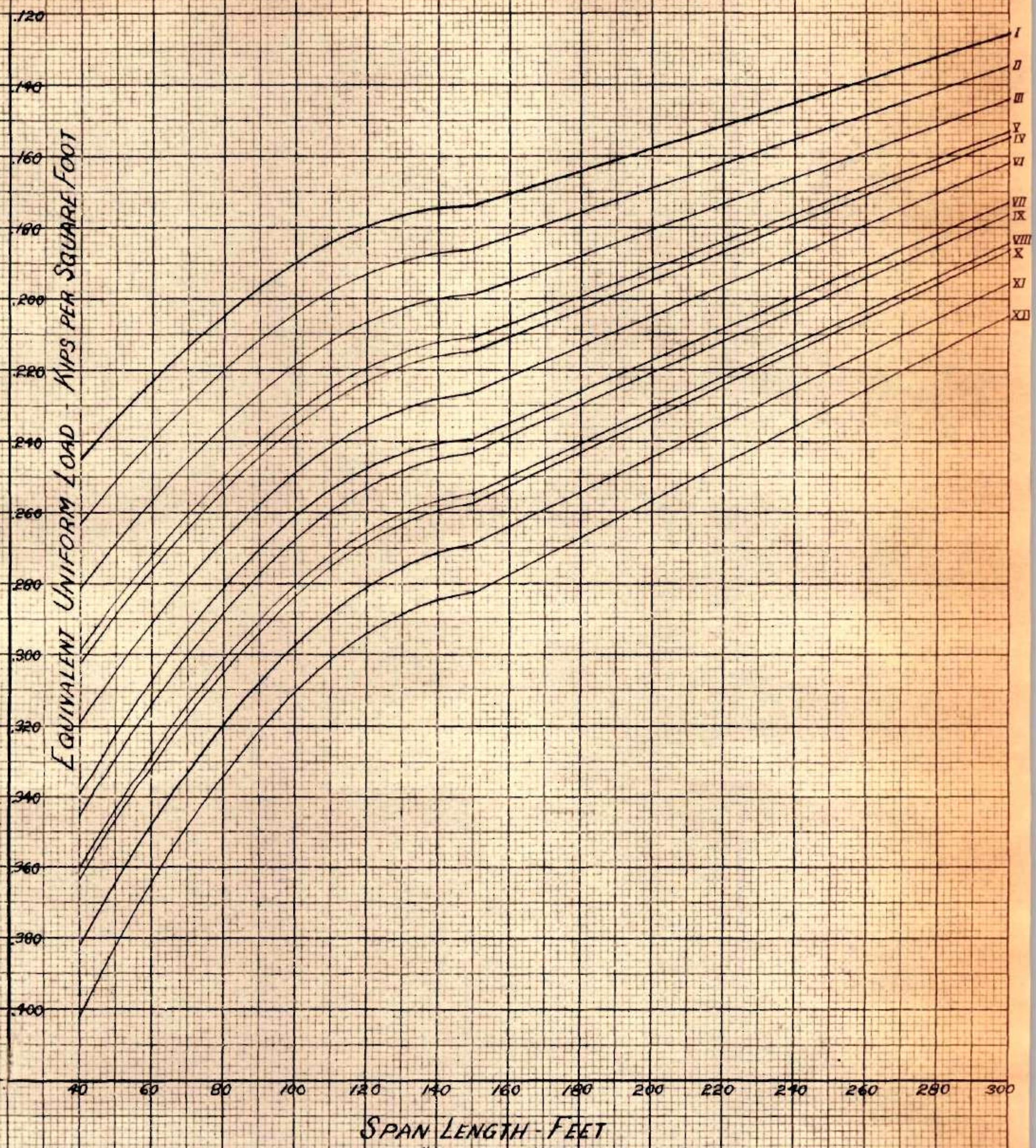


"FIG. 3"

EQUIVALENT UNIFORM LOAD FOR MOMENT

CLASS I BRIDGES

10 X 10 to the 1/2 inch, 5th lines accented.
MADE IN U.S.A.



"Fig. 4"

Equivalent Uniform Load for Shear

Class I Bridges

TABLE II.

EQUIVALENT UNIFORM LOAD IN KIPS PER SQUARE FOOT FOR CLASS I

BRIDGES

Span length	Moment Shear	Two Lanes 10FT.	11Ft.	12Ft.	13Ft.	Three Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	.316	.300	.285	.271	.284	.267	.251	.236
	V	.402	.382	.363	.346	.362	.339	.319	.300
60 Ft.	M	.254	.241	.229	.218	.228	.215	.202	.189
	V	.353	.335	.319	.3045	.318	.298	.280	.263
80 Ft.	M	.275	.261	.248	.236	.247	.232	.218	.205
	V	.353	.335	.2295	.304	.318	.2985	.280	.263
100 Ft.	M	.269	.256	.242	.231	.242	.227	.214	.201
	V	.312	.296	.282	.268	.281	.263	.248	.233
120 Ft.	M	.259	.246	.233	.222	.233	.219	.206	.193
	V	.290	.276	.262	.250	.262	.245	.230	.217
140 Ft.	M	.244	.232	.220	.209	.219	.206	.194	.182
	V	.269	.255	.243	.232	.242	.227	.214	.201
160 Ft.	M	.251	.238	.226	.215	.226	.212	.1995	.187
	V	.284	.270	.256	.239	.225	.239	.225	.212
180 Ft.	M	.252	.239	.227	.2165	.227	.213	.200	.188
	V	.273	.259	.247	.235	.246	.230	.217	.204
200 Ft.	M	.245	.232	.221	.210	.220	.207	.195	.183
	V	.262	.249	.237	.225	.236	.221	.208	.196
220 Ft.	M	.236	.224	.213	.202	.212	.199	.187	.176
	V	.250	.238	.226	.215	.225	.211	.198	.187
240 Ft.	M	.228	.216	.206	.195	.205	.193	.181	.170
	V	.238	.226	.215	.205	.215	.201	.189	.178
260 Ft.	M	.219	.208	.198	.188	.197	.185	.174	.164
	V	.227	.216	.205	.195	.205	.192	.180	.170
280 Ft.	M	.209	.198	.188	.179	.188	.175	.166	.156
	V	.216	.205	.195	.186	.194	.182	.171	.161
300 Ft.	M	.201	.191	.181	.172	.180	.170	.160	.150
	V	.206	.196	.186	.177	.1855	.174	.163	.154

TABLE II. (continued)

EQUIVALENT UNIFORM LOAD IN KIPS PER SQUARE FOOT FOR CLASS I BRIDGES

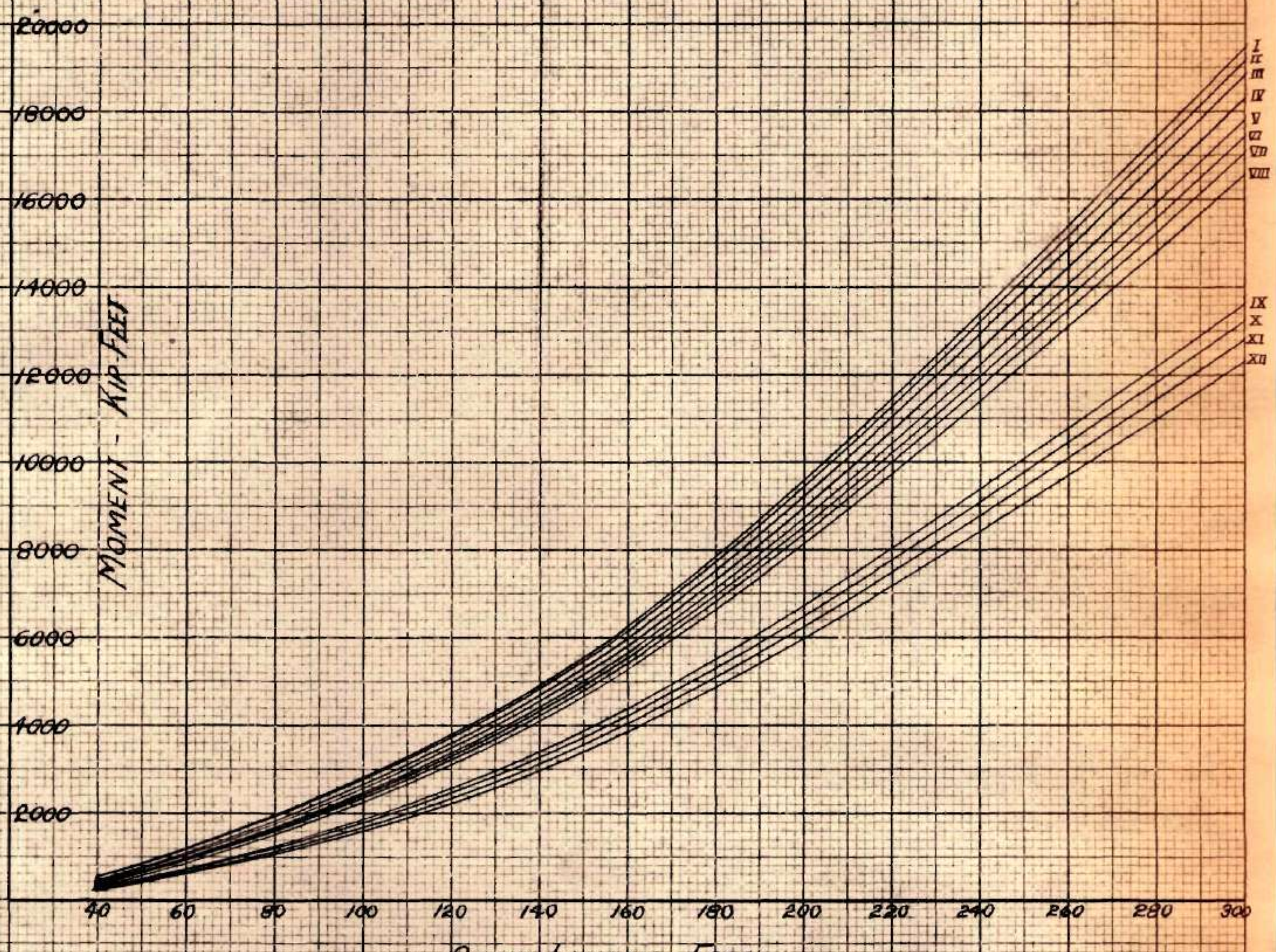
Span Length	Moment Shear	Four Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	.237	.221	.206	.193
	V	.302	.282	.263	.245
60 Ft.	M	.190	.178	.166	.155
	V	.265	.248	.231	.215
80 Ft.	M	.206	.192	.179	.1685
	V	.265	.248	.231	.215
100 Ft.	M	.202	.188	.176	.164
	V	.235	.219	.204	.190
120 Ft.	M	.194	.181	.169	.158
	V	.218	.203	.190	.177
140 Ft.	M	.183	.171	.159	.149
	V	.202	.189	.176	.164
160 Ft.	M	.188	.176	.164	.153
	V	.214	.199	.186	.173
180 Ft.	M	.189	.177	.165	.154
	V	.205	.192	.179	.166
200 Ft.	M	.184	.172	.160	.150
	V	.197	.184	.171	.160
220 Ft.	M	.177	.165	.154	.144
	V	.188	.175	.164	.152
240 Ft.	M	.171	.159	.149	.139
	V	.179	.167	.156	.145
260 Ft.	M	.164	.153	.143	.134
	V	.171	.159	.149	.138
280 Ft.	M	.157	.146	.136	.128
	V	.162	.151	.141	.132
300 Ft.	M	.151	.141	.131	.123
	V	.155	.145	.135	.126

increasing rate of increase for the moment curves and the decreasing rate of increase of the shear curves is the same as in the Class One bridges, and therefore need not be restated.

Table IV shows the equivalent uniform load required to produce the same maximum moments and shears as the actual wheel loads used in Class Two bridges.

Figures 7 and 8 are the equivalent uniform live load envelopes for Class II bridges. The discontinuity of the envelopes again appears at approximately the one hundred and forty foot mark. The explanation of this break in the envelope is the same as in Class One bridges and therefore will not be repeated. However, it will be noted that the break in the envelopes is not as sharp in this instance. This is due to the fact that the difference between the H20-S16 trucks and the H15-S12 trucks, used in the design of bridges in Class II, is relatively small compared to the difference between the H32-S35 trucks and H20-S16 trucks used in the design of the bridges in Class I.

The remaining tables and figures in this chapter represent the design moments and shears, and equivalent uniform envelopes for bridges falling within Class III. They can be compared with the present H15-S12 loadings just as the design moments and shears in Class II were compared with the present H20-S16 loading results.



"FIG. 5"

DESIGN MOMENTS

CLASS II BRIDGES

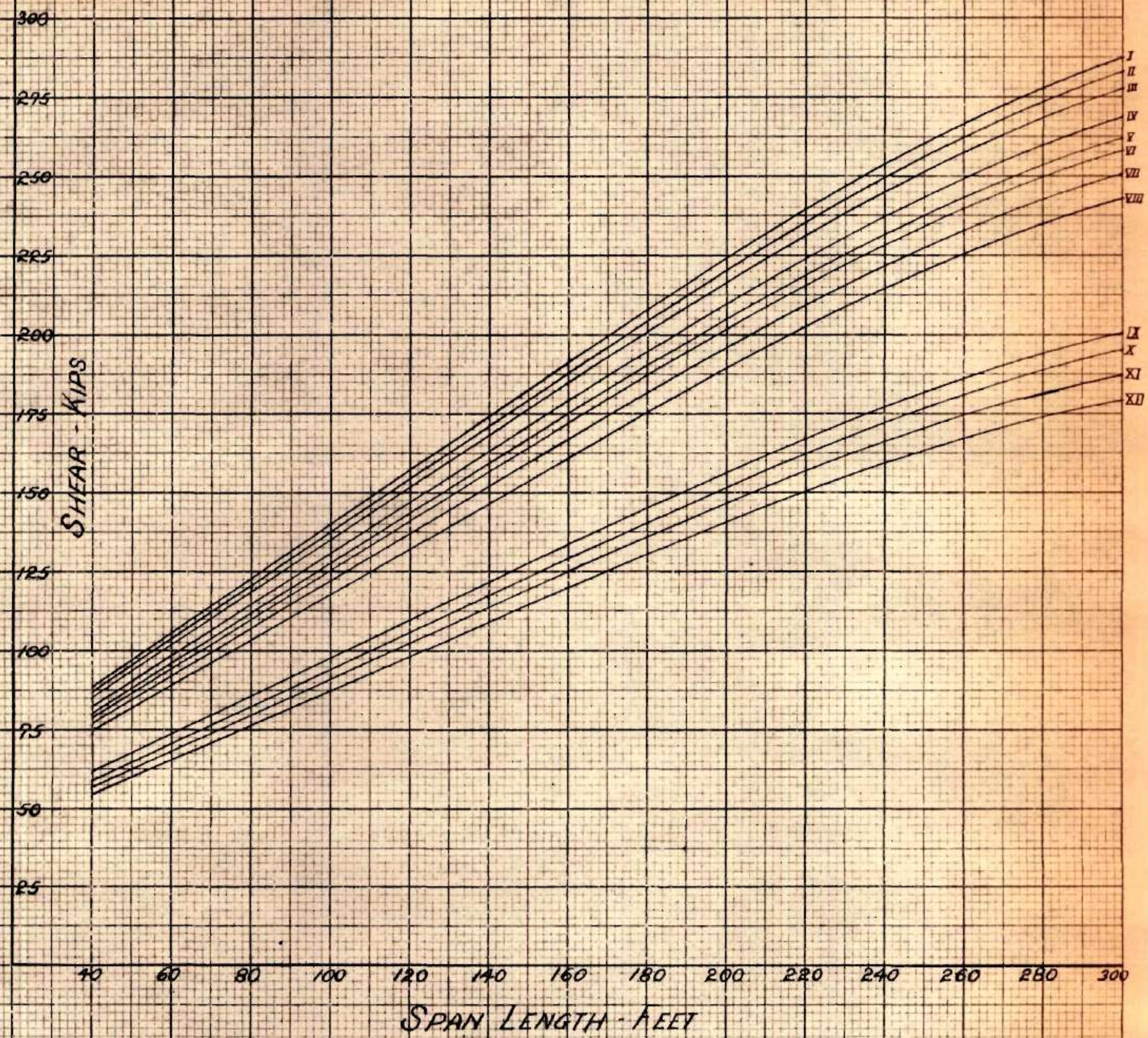


FIG. 6
DESIGN SHEARS
CLASS II BRIDGES

TABLE III.

DESIGN MOMENTS AND SHEARS FOR CLASS II BRIDGES

Span Length	Moment* Shear	Two Lanes 10Ft.	11Ft.	12Ft.	13Ft.	Three Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	336	352	364	375	454	468	478	488
	V	55	58	60	62	74	77	79	81
60 Ft.	M	682	713	739	761	922	950	970	990
	V	62	65	67	69	83	87	89	90
80 Ft.	M	1165	1220	1262	1300	1575	1624	1660	1692
	V	76	79	82	82	102	106	109	110
100 Ft.	M	1600	1678	1735	1786	2169	2230	2280	2320
	V	89	93	96	99	120	124	127	129
120 Ft.	M	2288	2390	2480	2550	3090	3190	3260	3320
	V	98	102	106	109	132	137	140	143
140 Ft.	M	3000	3140	3250	3350	4060	4180	4270	4360
	V	104	108	112	116	140	145	149	152
160 Ft.	M	3920	4110	4250	4380	5300	5460	5590	5700
	V	121	126	131	135	163	169	173	176
180 Ft.	M	4928	5160	5340	5500	6660	6860	7030	7160
	V	130	136	141	145	173	182	186	190
200 Ft.	M	5930	6210	6420	6610	8000	8260	8440	8600
	V	141	147	152	157	190	197	202	206
220 Ft.	M	6630	6950	7180	7400	8960	9250	9440	9630
	V	151	157	163	169	203	211	217	220
240 Ft.	M	8510	8910	9210	9500	11500	11840	12100	12350
	V	159	166	172	177	214	222	228	232
260 Ft.	M	9370	10200	10550	10850	13120	13550	13850	14120
	V	167	174	180	186	225	233	240	244
280 Ft.	M	11010	11520	11920	12300	14900	15350	15700	16000
	V	173	180	187	193	233	242	248	252
300 Ft.	M	12310	12900	13350	13720	16600	17120	17500	17900
	V	181	189	196	202	244	253	260	264

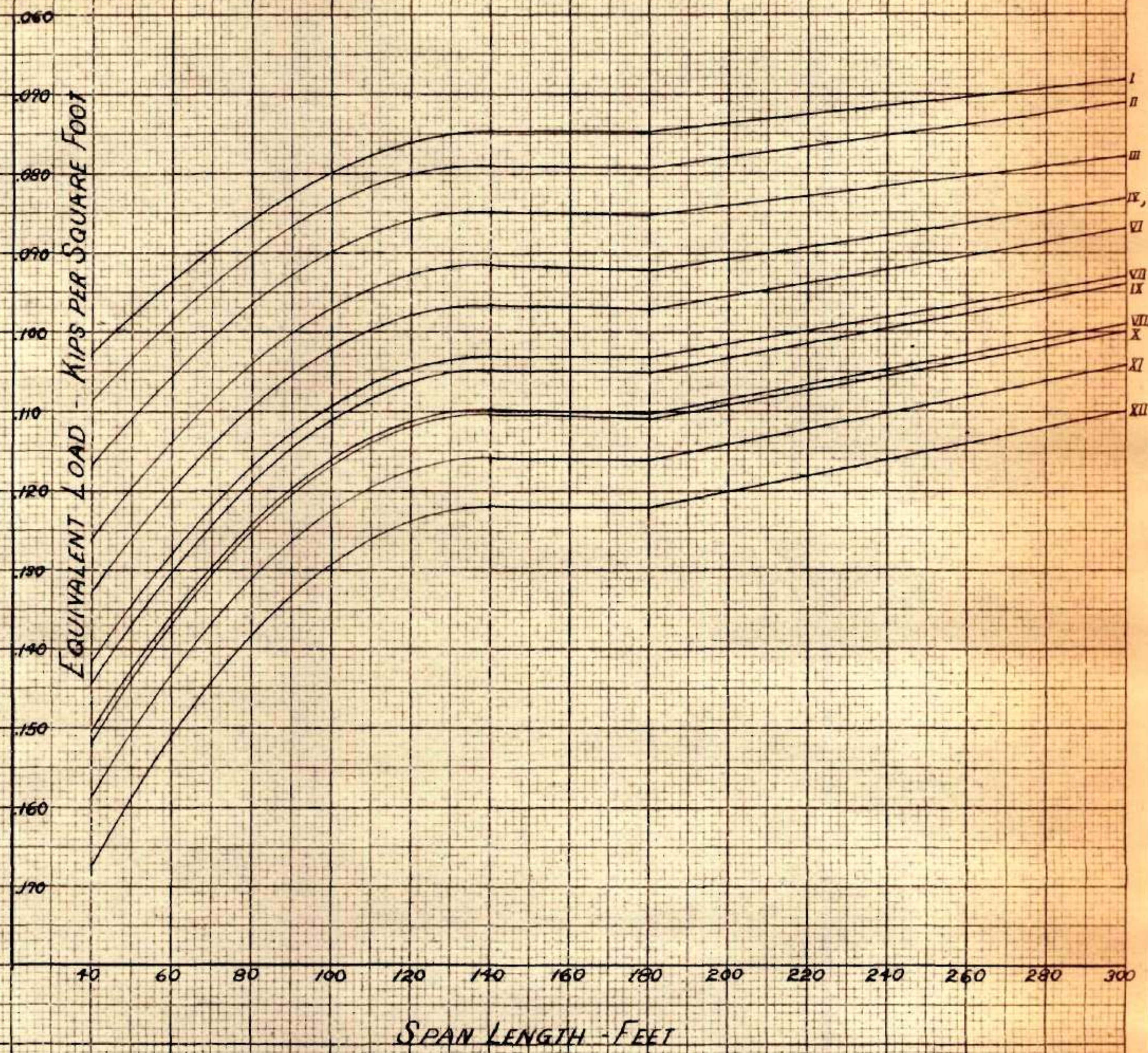
*All moments in kip-feet units.

All shears in kip units.

TABLE III (continued)

DESIGN MOMENTS AND SHEARS FOR CLASS II BRIDGES

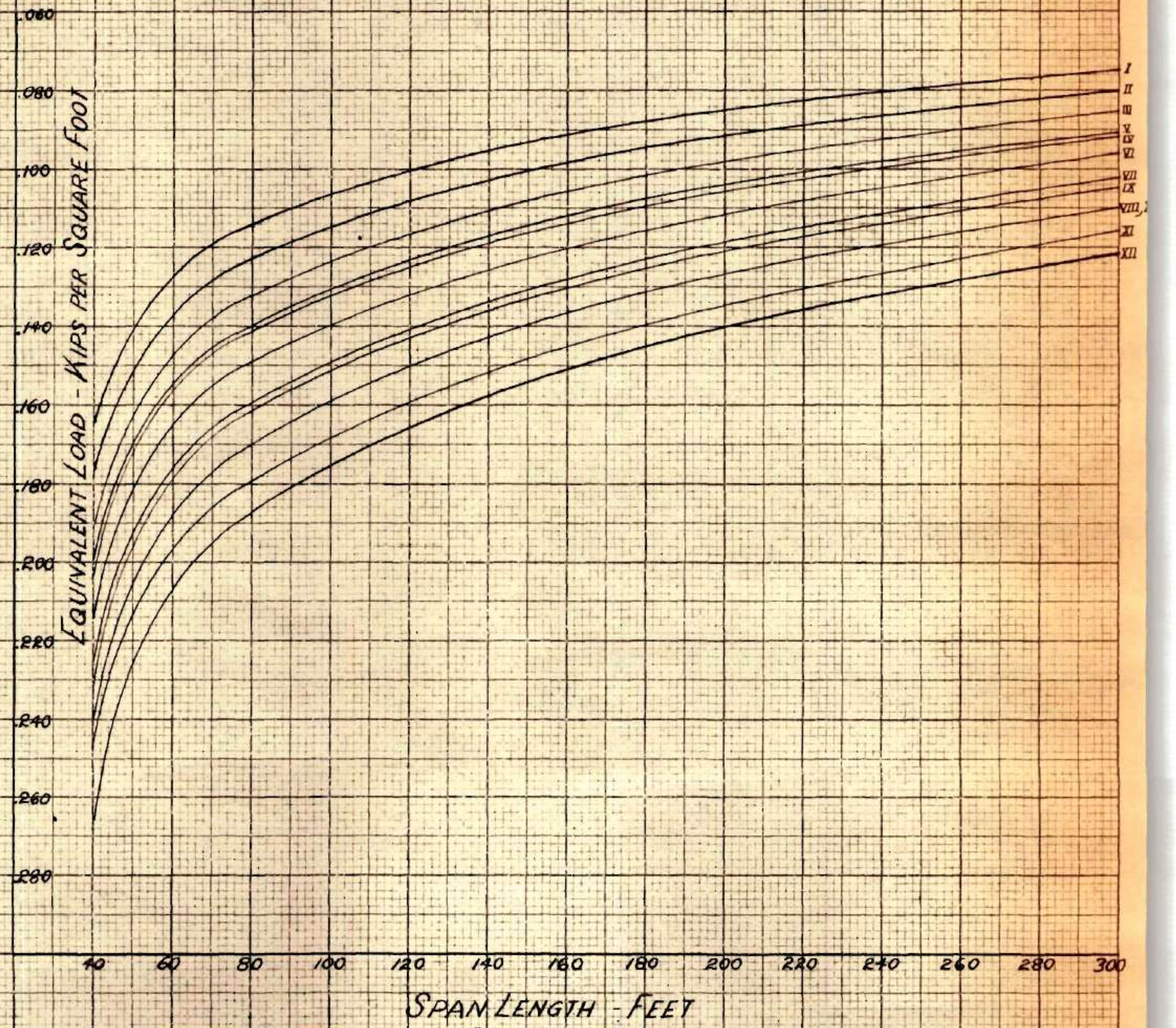
Span Length	Moment Shear	Four Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	504	516	526	535
	V	83	85	87	88
60 Ft.	M	1022	1048	1069	1086
	V	93	96	97	99
80 Ft.	M	1748	1790	1822	1856
	V	113	117	119	121
100 Ft.	M	2400	2460	2505	2550
	V	133	137	139	142
120 Ft.	M	3430	3510	3580	3640
	V	147	151	154	156
140 Ft.	M	4500	4610	4700	4780
	V	156	160	163	166
160 Ft.	M	5880	6020	6140	6250
	V	181	187	190	193
180 Ft.	M	7390	7560	7710	7850
	V	194	201	204	207
200 Ft.	M	8890	9100	9270	9440
	V	211	218	221	225
220 Ft.	M	9940	10180	10380	10550
	V	226	234	237	241
240 Ft.	M	12750	13050	13300	13550
	V	238	246	250	254
260 Ft.	M	14600	14920	15200	15500
	V	250	258	262	266
280 Ft.	M	16500	16900	17250	17550
	V	259	267	272	276
300 Ft.	M	18450	18900	19250	19600
	V	271	280	284	289



"Fig. 7"

Equivalent Uniform Load for Moment

Class II Bridges



"FIG. 8"

EQUIVALENT UNIFORM LOAD FOR SHEAR

CLASS II BRIDGES

TABLE IV

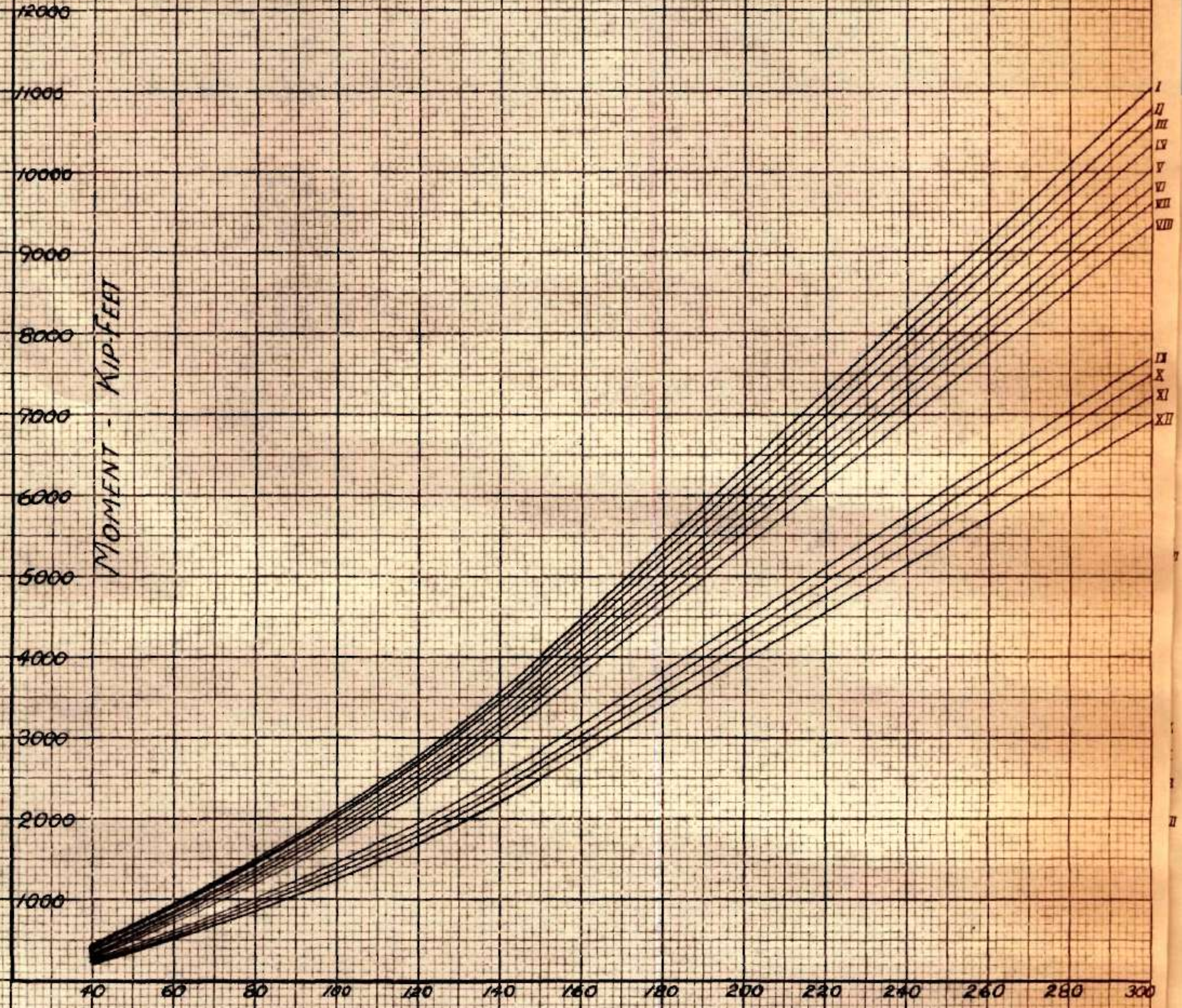
EQUIVALENT UNIFORM LOAD IN KIPS PER SQUARE FOOT FOR CLASS II BRIDGES

Span Length	Moment Shear	Two Lanes 10Ft.	11Ft.	12Ft.	13Ft.	Three Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	.168	.159	.152	.144	.151	.142	.133	.126
	V	.276	.262	.249	.237	.248	.233	.219	.206
60 Ft.	M	.151	.143	.136	.130	.136	.128	.119	.113
	V	.206	.195	.186	.177	.185	.174	.163	.154
80 Ft.	M	.146	.138	.132	.125	.131	.123	.116	.109
	V	.189	.180	.171	.162	.170	.160	.150	.141
100 Ft.	M	.128	.121	.116	.110	.115	.108	.101	.096
	V	.178	.170	.161	.153	.160	.150	.141	.133
120 Ft.	M	.127	.120	.115	.109	.114	.107	.101	.095
	V	.163	.155	.147	.1405	.147	.138	.129	.122
140 Ft.	M	.122	.116	.110	.105	.110	.103	.097	.092
	V	.149	.141	.134	.128	.134	.126	.118	.111
160 Ft.	M	.122	.116	.111	.105	.110	.103	.097	.092
	V	.151	.143	.136	.130	.136	.128	.120	.113
180 Ft.	M	.122	.116	.111	.105	.110	.103	.097	.092
	V	.145	.138	.131	.125	.127	.119	.112	.105
200 Ft.	M	.119	.113	.108	.102	.107	.101	.094	.089
	V	.141	.134	.1275	.121	.127	.119	.112	.105
220 Ft.	M	.110	.104	.100	.094	.099	.093	.087	.083
	V	.137	.130	.124	.118	.123	.116	.109	.102
240 Ft.	M	.118	.112	.107	.101	.106	.100	.093	.089
	V	.133	.126	.120	.114	.120	.112	.106	.099
260 Ft.	M	.115	.109	.104	.099	.103	.097	.091	.086
	V	.128	.122	.116	.110	.115	.108	.102	.096
280 Ft.	M	.112	.106	.101	.096	.101	.095	.089	.084
	V	.124	.118	.112	.107	.111	.105	.098	.093
300 Ft.	M	.110	.104	.100	.094	.099	.093	.087	.083
	V	.121	.115	.109	.1045	.109	.102	.096	.090

TABLE IV (continued)

EQUIVALENT UNIFORM LOAD IN KIPS PER SQUARE FOOT FOR CLASS II BRIDGES

Span Length	Moment Shear	Four Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	.126	.117	.109	.103
	V	.207	.194	.181	.168
60 Ft.	M	.113	.105	.098	.093
	V	.154	.145	.135	.125
80 Ft.	M	.109	.102	.095	.090
	V	.142	.133	.124	.115
100 Ft.	M	.096	.089	.083	.078
	V	.133	.125	.117	.108
120 Ft.	M	.095	.089	.082	.078
	V	.122	.115	.107	.099
140 Ft.	M	.092	.085	.079	.075
	V	.111	.105	.098	.091
160 Ft.	M	.092	.085	.079	.075
	V	.113	.106	.099	.092
180 Ft.	M	.092	.085	.079	.075
	V	.108	.102	.095	.088
200 Ft.	M	.089	.083	.077	.073
	V	.106	.099	.092	.086
220 Ft.	M	.083	.077	.071	.068
	V	.103	.096	.090	.083
240 Ft.	M	.089	.082	.077	.072
	V	.100	.094	.087	.081
260 Ft.	M	.086	.080	.075	.071
	V	.096	.090	.084	.078
280 Ft.	M	.084	.078	.073	.069
	V	.093	.087	.081	.076
300 Ft.	M	.083	.078	.071	.068
	V	.091	.085	.079	.074

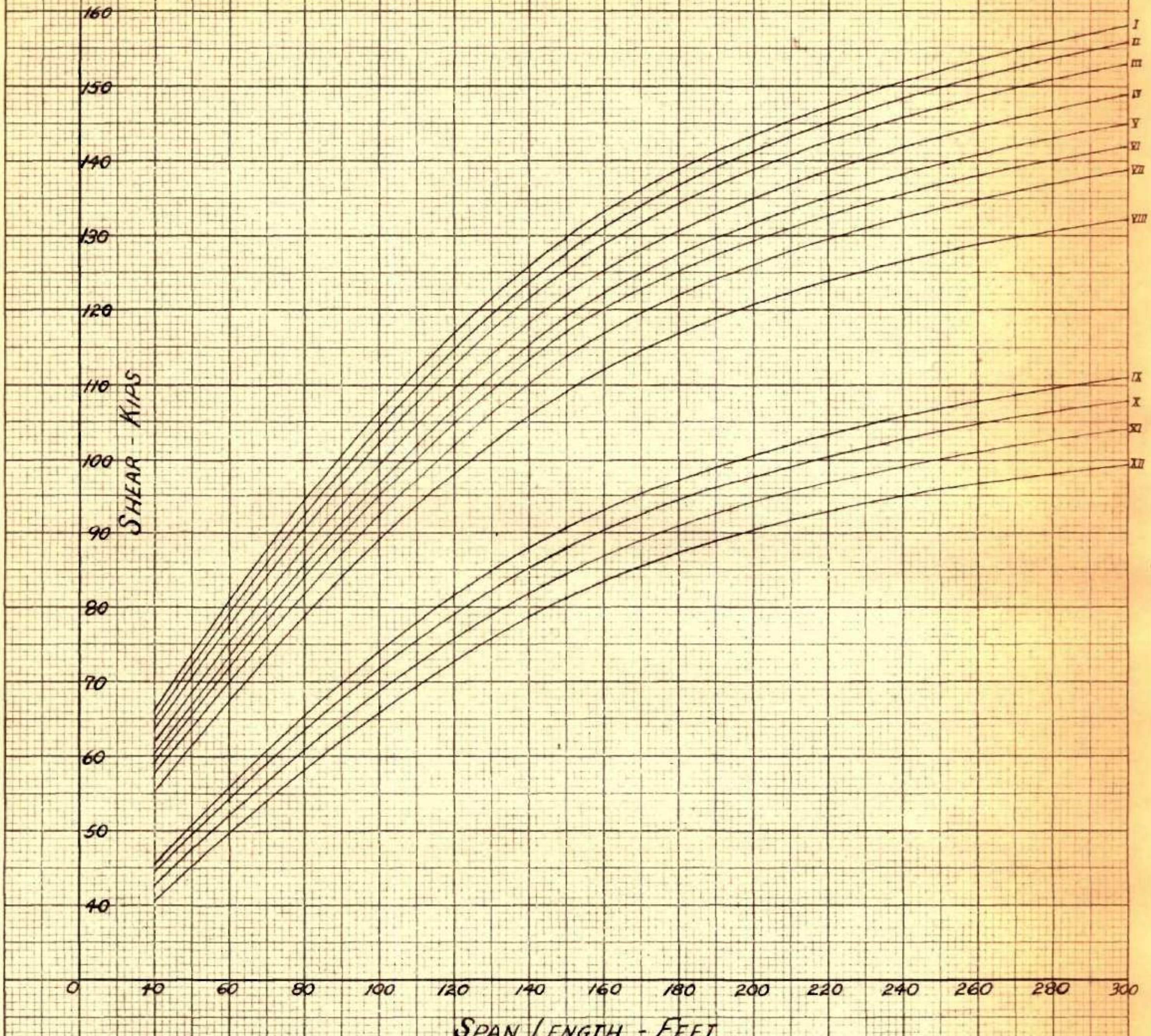


SPAN LENGTH - FEET

"FIG. 9"

DESIGN MOMENTS

CLASS III BRIDGES



"FIG. 10"

DESIGN SHEARS

CLASS III BRIDGES

TABLE V

DESIGN MOMENTS AND SHEARS FOR CLASS III BRIDGES

Span Length	Moment* Shear	Two Lanes 10Ft.	11Ft.	12Ft.	13Ft.	Three Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	252	264	273	281	341	351	358	366
	V	41	43	45	46	56	58	59	60
60 Ft.	M	512	535	554	571	692	712	728	742
	V	46	49	50	52	64	65	67	68
80 Ft.	M	875	915	948	975	1180	1220	1245	1270
	V	57	59	62	63	75	80	82	83
100 Ft.	M	1200	1258	1300	1340	1620	1670	1710	1728
	V	67	70	72	74	90	93	95	97
120 Ft.	M	1718	1790	1860	1910	2320	2390	2450	2490
	V	73	77	80	82	99	103	105	107
140 Ft.	M	2250	2350	2440	2510	3040	3140	3200	3270
	V	78	81	84	87	105	109	112	114
160 Ft.	M	2780	2910	3010	3100	3760	3870	3950	4040
	V	83	87	90	93	112	117	120	122
180 Ft.	M	3360	3520	3640	3750	4550	4680	4770	4880
	V	87	91	94	97	117	120	125	127
200 Ft.	M	3950	4140	4280	4400	5350	5500	5610	5740
	V	90	94	98	101	121	126	130	132
220 Ft.	M	4550	4770	4940	5070	6160	6340	6460	6610
	V	91	95	99	102	123	128	131	133
240 Ft.	M	5130	5380	5560	5720	6940	7150	7280	7450
	V	95	99	103	106	127	132	136	138
260 Ft.	M	5730	6000	6210	6390	7760	7990	8140	8320
	V	97	101	105	108	130	135	141	142
280 Ft.	M	6330	6640	6850	7050	8560	8810	8980	9190
	V	98	102	106	109	131	137	140	143
300 Ft.	M	6930	7260	7510	7740	9390	9660	9860	10080
	V	99	104	108	111	133	139	142	145

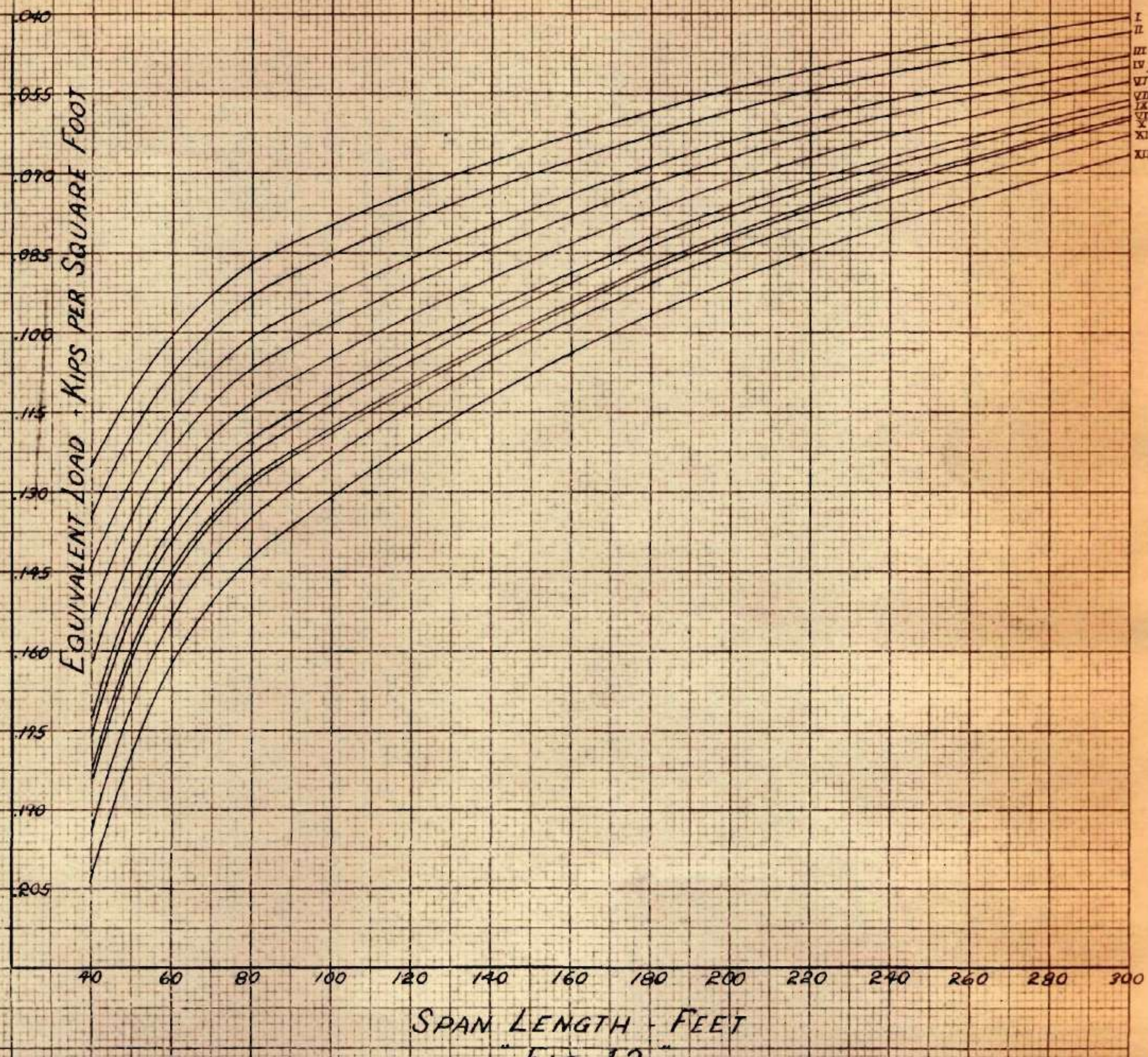
*All moments in kip-feet units.

All shears in kip units.

TABLE V (continued)

DESIGN MOMENTS AND SHEARS FOR CLASS III BRIDGES

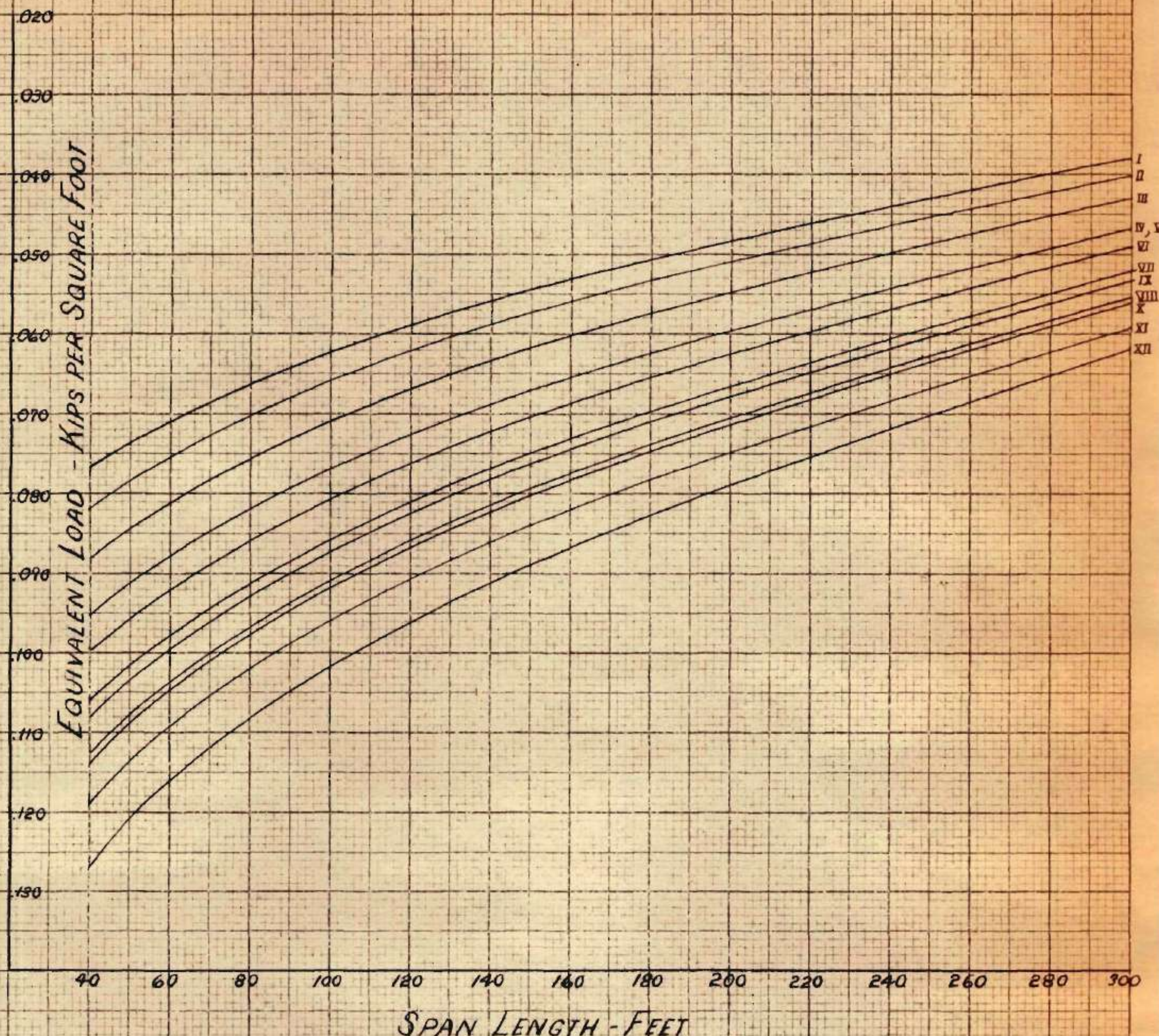
Span Length	Moment Shear	Four Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	378	387	395	402
	V	62	64	65	66
60 Ft.	M	768	786	802	815
	V	70	72	73	74
80 Ft.	M	1310	1342	1370	1390
	V	85	89	90	91
100 Ft.	M	1800	1845	1880	1910
	V	100	103	104	107
120 Ft.	M	2570	2630	2690	2730
	V	110	113	115	117
140 Ft.	M	3370	3460	3520	3580
	V	117	120	122	125
160 Ft.	M	4170	4270	4360	4440
	V	125	129	131	133
180 Ft.	M	5040	5160	5270	5360
	V	130	135	137	139
200 Ft.	M	5920	6070	6190	6300
	V	135	140	142	144
220 Ft.	M	6830	6990	7140	7250
	V	137	141	143	146
240 Ft.	M	7690	7890	8040	8160
	V	142	146	149	151
260 Ft.	M	8600	8800	8980	9140
	V	145	150	152	155
280 Ft.	M	9480	9710	9910	10100
	V	146	151	153	156
300 Ft.	M	10400	10650	10880	11050
	V	149	153	156	158



"Fig. 12"

Equivalent Uniform Load for Shear

Class III Bridges



"Fig. 11"

Equivalent Uniform Load for Moment

Class III Bridges

TABLE VI.

EQUIVALENT UNIFORM LOAD IN KIPS PER SQUARE FOOT FOR CLASS III BRIDGES

Span Length	Moment Shear	Two Lanes 10Ft.	11Ft.	12Ft.	13Ft.	Three Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	.126	.119	.114	.108	.113	.106	.100	.095
	V	.207	.197	.187	.178	.186	.175	.164	.155
60 Ft.	M	.113	.107	.102	.097	.102	.096	.089	.085
	V	.155	.146	.140	.133	.139	.130	.122	.115
80 Ft.	M	.109	.104	.099	.094	.098	.092	.087	.082
	V	.142	.135	.128	.122	.127	.120	.113	.106
100 Ft.	M	.097	.091	.087	.083	.086	.081	.076	.072
	V	.134	.127	.121	.115	.120	.113	.106	.100
120 Ft.	M	.096	.090	.086	.082	.086	.080	.076	.071
	V	.122	.116	.110	.105	.110	.104	.097	.092
140 Ft.	M	.092	.087	.083	.079	.083	.077	.073	.069
	V	.112	.106	.101	.096	.101	.096	.089	.083
160 Ft.	M	.087	.082	.079	.075	.078	.073	.069	.066
	V	.104	.097	.094	.090	.094	.088	.083	.078
180 Ft.	M	.083	.078	.075	.071	.070	.069	.066	.064
	V	.097	.092	.088	.083	.087	.082	.077	.073
200 Ft.	M	.079	.075	.072	.068	.071	.067	.063	.060
	V	.090	.086	.081	.077	.081	.076	.071	.067
220 Ft.	M	.075	.071	.068	.064	.067	.063	.060	.057
	V	.083	.079	.075	.071	.075	.070	.066	.062
240 Ft.	M	.071	.067	.064	.061	.064	.060	.056	.054
	V	.079	.075	.071	.068	.071	.067	.063	.059
260 Ft.	M	.068	.064	.062	.058	.061	.057	.054	.051
	V	.074	.070	.067	.064	.066	.063	.059	.055
280 Ft.	M	.065	.062	.059	.056	.058	.055	.052	.049
	V	.070	.067	.063	.060	.063	.059	.056	.052
300 Ft.	M	.062	.059	.056	.053	.056	.052	.050	.047
	V	.066	.063	.060	.057	.059	.056	.052	.049

TABLE VI (continued)

EQUIVALENT UNIFORM LOAD IN KIPS PER SQUARE FOOT FOR CLASS III BRIDGES

Span Length	Moment Shear	Four Lanes 10Ft.	11Ft.	12Ft.	13Ft.
40 Ft.	M	.095	.088	.082	.077
	V	.155	.146	.136	.126
60 Ft.	M	.086	.078	.073	.070
	V	.115	.109	.101	.094
80 Ft.	M	.082	.077	.071	.068
	V	.106	.100	.093	.086
100 Ft.	M	.072	.068	.062	.059
	V	.100	.094	.088	.081
120 Ft.	M	.071	.067	.062	.059
	V	.092	.086	.080	.074
140 Ft.	M	.069	.064	.059	.056
	V	.083	.079	.075	.068
160 Ft.	M	.066	.061	.057	.053
	V	.078	.074	.068	.063
180 Ft.	M	.064	.058	.054	.051
	V	.073	.068	.064	.059
200 Ft.	M	.060	.055	.051	.048
	V	.067	.064	.059	.055
220 Ft.	M	.057	.052	.049	.046
	V	.062	.059	.055	.051
240 Ft.	M	.054	.050	.046	.043
	V	.059	.050	.046	.043
260 Ft.	M	.051	.048	.044	.042
	V	.055	.052	.049	.045
280 Ft.	M	.049	.045	.042	.040
	V	.052	.049	.046	.043
300 Ft.	M	.047	.043	.040	.038
	V	.049	.047	.043	.040

CHAPTER III

The design moments and shears, that have been tabulated and diagramed in the preceding chapters, are for simple spans only. I have corrected the first two discrepancies between the actual vehicle loads and the present loading standard by introducing a new type of truck loading known as the H32-S35 (See appendix) and the addition of more than one truck in the determination of design moments and shears for the longer spans.

However, for the purpose of simplification of calculations required in the determination of maximum design conditions, the equivalent uniform live loadings proposed by this paper, have been established without the inclusion of concentrated loads. The majority of bridge designers will accept this loading for simple spans since it will produce the same maximum values as a partial uniform load and a center concentration.

In the case of continuous spans, however, the concentrated loads used today can be so placed as to produce maximum negative moments over the interior supports. This cannot be done with the simple equivalent uniform live loads that I have proposed.

If it could be shown that the moments determined by using the present day uniform lane loadings plus concentrated loads were insignificant compared to those moments determined by using the equivalent loadings proposed in this paper, the addition of a concentrated load or concentrated loads for continuous spans would be unnecessary.

Several sample designs were run comparing the moments and shears obtained by using the equivalent uniform loads advocated in this paper with those moments and shears determined by using lane loads and two concentrated loads. In comparing the values acquired by using the equivalent loads for Class II bridges with those found using H20-S16 loadings, it was found that the maximum negative moments and shears were higher using the equivalent uniform live load proposed by this paper, for spans greater than one hundred feet. In comparing the loads used for Class I bridges to the H20-S16 loadings, the values for moments and shears were higher, using the equivalent live loads for Class I bridges, for all span lengths.

These results support the writers contention that the simple equivalent live loads proposed in this paper may be used for both simple and continuous spans.

CHAPTER IV

With the introduction of new truck loadings, a reclassification of bridges, the development of design shear and moment tables and equivalent uniform live load envelopes, your writer has satisfied the purpose of this paper. However, he feels that the problem of design could be simplified to a still greater extent by the derivation of simple equations for the equivalent uniform load envelopes and moment and shear curves. In most cases the curves could be represented by one or two straight line equations which would give safe values in all cases.

To derive equations for all one hundred and twenty curves found in this paper would be a time consuming task. Unfortunately, this time is not available to your writer. He has, therefore, derived the equations for curve number I on each figure found in the paper.

These equations are as follows:

Figure 1, Span lengths of 40 to 150 feet.

1) $X^2 = 1.7\ Y$

Span lengths of 150 to 300 feet.

2) $164\ X - Y - 13200 = 0$

Figure 2, Span lengths of 40 to 180 feet.

3) $2.05\ X - Y + 46 = 0$

Figure 2, Span lengths of 180 to 300 feet.

4) $0.64\ X - Y + 294 = 0$

Figure 3, Span lengths of 40 to 300 feet.

5) $0.000114\ X + Y - 0.155 = 0$

Figure 4, Span lengths of 40 to 110 feet.

6) $0.00088\ X + Y - 0.275 = 0$

Span lengths of 110 to 300 feet.

7) $0.000281\ X + Y - 0.210 = 0$

Figure 5, Span lengths of140 to 300 feet.

8) $92.5\ X - Y + 75 - 8175 = 0$

Span lengths of 40 to 140 feet.

9) $42\ X - Y - 1080 = 0$

Figure 6, Span lengths of 40 to 300 feet.

10) $0.735\ X - Y + 79 = 0$

Figure 7, Span lengths of 40 to 140 feet.

11) $0.00023\ X - Y - 0.102 = 0$

Span lengths of 140 to 300 feet.

12) $0.000019\ X + Y - 0.0727 = 0$

Figure 8, Span lengths of 40 to 60 feet.

13) $0.0045\ X + Y - 0.386 = 0$

Span lengths of 60 to 300 feet.

14) $0.000168\ X + Y - 0.116 = 0$

Figure 9, Span lengths of 40 to 140 feet.

15) $32\ X - Y - 880 = 0$

Span lengths of 140 to 300 feet.

16) $46.8\ X - Y - 3000 = 0$

Figure 10, Span lengths of 40 to 145 feet.

17) $0.67\ X - Y + 43.2 = 0$

Span lengths of 145 to 300 feet.

18) $0.13\ X - Y + 121.2 = 0$

Figure 11, Span lengths of 40 to 300 feet.

19) $0.000123\ X + Y - 0.072 = 0$

Figure 12, Span lengths of 40 to 80 feet.

20) $0.001\ X + Y - 0.158 = 0$

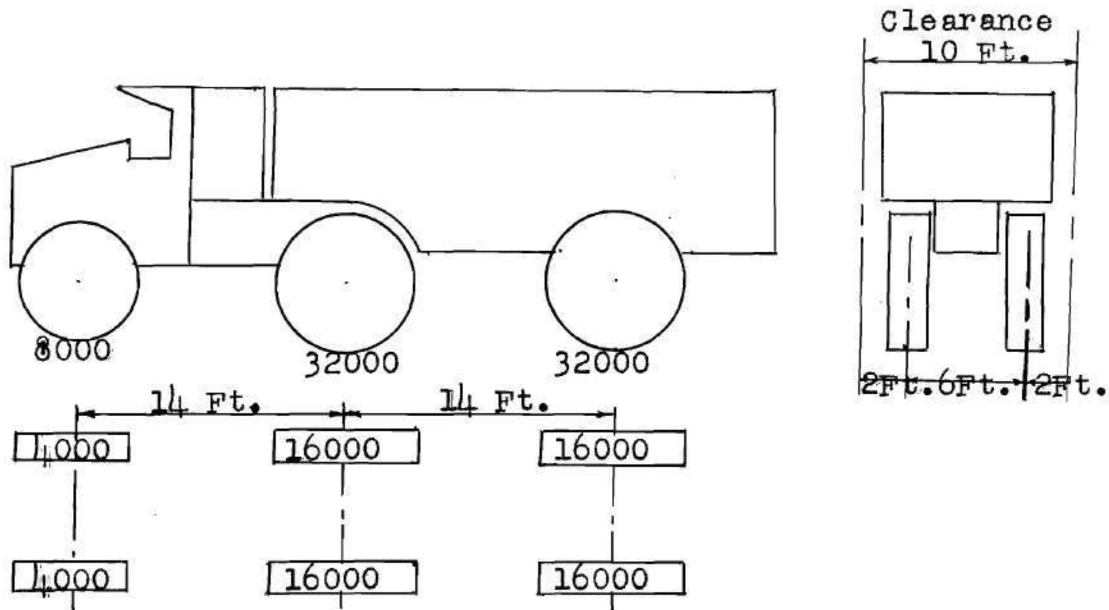
Span lengths of 80 to 300 feet.

21) $0.00021\ X + Y - 0.095 = 0$

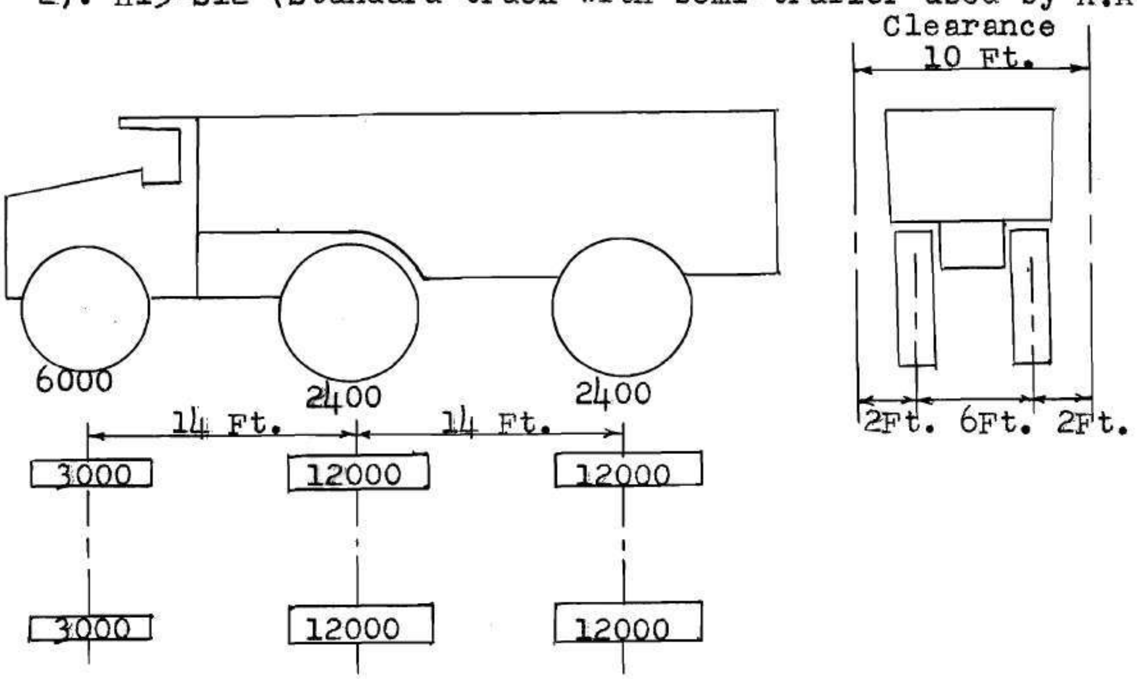
APPENDIX

TYPES OF VEHICLES USED IN CALCULATIONS.

1). H20-S16 (Standard truck with semi-trailor used by A.A.S.H.O.)



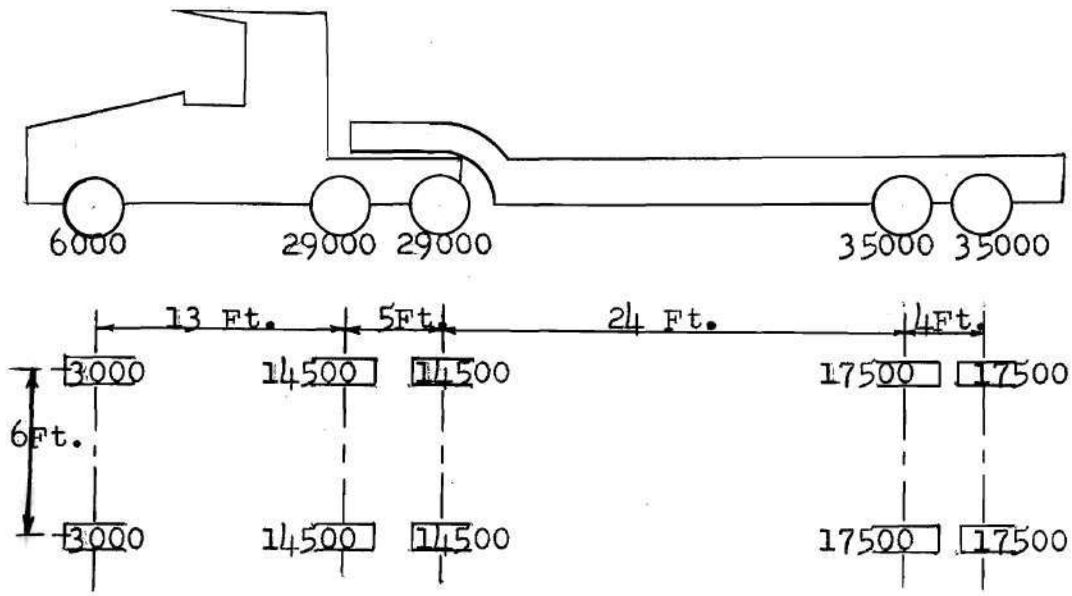
2). H15-S12 (Standard truck with semi-trailor used by A.A.S.H.O.)



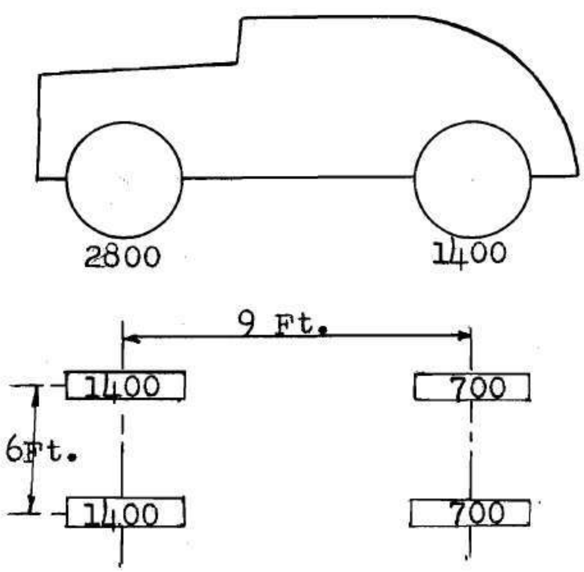
All wheel and axle loads are in pound units.

TYPES OF TRUCKS (continued)

3). H32-S35 (Trucks comparable to those found on highways today.)



4(. A-10 (Standard passenger vehicle).



All wheel and axle loads in pound units.

CLASSIFICATION OF BRIDGES

CLASS I. INDUSTRIAL BRIDGES

This type of bridges pertains to all spans normally carrying extremely heavy trucking loads. All municipal bridges, municipal approaches, port approaches, and spans situated near large industrial plants, dealing with the transportation of heavy machinery and finished products such as automobiles, etc.

All bridges in Class I with span lengths of less than one hundred and fifty feet shall be designed using H32-S35 trucks, exclusively.

All bridges in Class I with span lengths of one hundred and fifty to three hundred feet shall be designed using two H32-S35 trucks and two H20-S16 trucks, placed to produce maximum conditions.

Due to the possibility of tie-ups due to congestion on this type of bridge, the trucks shall be placed at five foot intervals.

CLASSIFICATION OF BRIDGES

CLASS II. ROUTE BRIDGES

This type of bridge includes a vast majority of the bridges built today including all those located on interstate highways experiencing normal interstate trucking loads.

All bridges in Class II with span lengths of less than one hundred and fifty feet shall be designed using two H20-S16 trucks, exclusively.

All bridges in Class II with span lengths of one hundred and fifty to three hundred feet shall be designed using two H20-S16 trucks and two H15-S12 trucks , placed to produce maximum conditions.

The spacing of trucks shall be a nominal thirty foot interval for all bridges within Class II.

CLASSIFICATION OF BRIDGES

CLASS III. RURAL BRIDGES

This type of bridge pertains to lightly traveled structures which, in all likelyhood, will never experience heavy truck loads. No state or municipal bridges would be allowed to be designed under specifications developed for this class of bridge. This type would include bridges on private estates, etc.

All bridges in CLASS III with span lengths of less than one hundred and fifty feet shall be designed using two H15-S12 trucks, exclusively.

All bridges in CLASS III with span lengths of one hundred and fifty to three hundred feet shall be designed using two H15-12S trucks and two A-10 automobiles, placed to produce maximum conditions.

The spacing of vehicles shall be a nominal thirty foot interval for all bridges within CLASS III.

Determination of maximum moments and shears for one hundred foot span, two lanes, each lane thirteen feet wide, for Class I bridge; showing comparison of proposed loadings in this paper to U 1600 loadings suggested by T.Y. Lin, and A.A.S.H.O. standards.

Using figures and tables proposed in this paper.

Maximum design moment = 3750 Kip-Feet.

Maximum design shear = 174 Kips.

Using A.A.S.H.O. H20-S16 loadings.

Maximum design moment = 1784 Kip-Feet.

Maximum design shear = 80 Kips.

Using T.Y. Lin's equivalent to A.A.S.H.O. H20-S16 loadings.

Maximum design moment = 4010 Kip=Feet.

Maximum design shear = 160 Kips.

Determination of maximum design moments and shears for eighty foot span, two lanes, each lane twelve feet wide.
Class II bridge.

Using figures and tables proposed in this paper.

Maximum design moment = 1262 Kip=Feet.

Maximum design shear = 82 Kips.

Using A.A.S.H.O. H20-S16 loadings.

Maximum design moments = 1250 Kip-Feet.

Maximum design shear = 71 Kips.

Using T.Y. Lin's equivalent to A.A.S.H.O. H20-S16 loading.

Maximum design moment =1388 Kip-Feet.

Maximum design shear = 69 Kips.

Determination of maximumdesign moments and shears for a two hundred and sixty foot span, three lanes, each lane ten feet wide. Class II bridge.

Using figures and tables proposed by this paper.

Maximum design moment = 13120 Kip-Feet.

Maximum design shear = 225 Kips.

Using A.A.S.H.O. H20-S16 loadings.

Maximum design moment = 11120 Kip-Feet.

Maximum design shear = 167 Kips.

Using T.Y. Lin's equivalent to A.A.S.H.O. H20- S16 loadings.

Maximum design moment = 13240 Kip-Feet.

Maximum design shear = 193 Kips.

APPLICATION OF PROPOSED LOADING TO CONTINUOUS SPANS

Two span lengths, each one hundred feet; two, ten foot wide lanes. Class II bridge.

Using equivalent uniform loads proposed in this paper.

Maximum design moment = 397 Kip-Feet.

Maximum design shear = 111 Kips.

Using A.A.S.H.O. H20-S16 loadings.

Maximum design moment = 504 Kip-Feet.

Maximum design shear = 80 Kips.

Two span lengths, each two hundred and sixty feet; two lanes,each ten feet wide.

Using equivalent uniform loads proposed in this paper.

Maximum design moment = 2410 Kip-Feet.

Maximum design shear = 208 Kips.

Using A.A.S.H.O. H20-S16 loading.

Maximum design moment = 2165 Kip-Feet.

Maximum design shear = 144 Kips.

APPLICATION OF PROPOSED LOADINGS TO CONTINUOUS SPANS

Two span lengths, each sixty feet; two,ten foot wide lanes. Class I bridge.

Using equivalent uniform loads proposed in this paper.

Maximum design moment = 284 Kip-Feet.

Maximum design shear = 132 Kips.

Using A.A.S.H.O. H20-S16 loading.

Maximum design moment = 256 Kip-Feet.

Maximum design shear = 64 Kips.

Two span lengths, each three hundred feet; two, ten foot wide lanes. Class I bridge.

Using equivalent uniform loads proposed in this paper.

Maximum design moment = 5600 Kip-Feet.

Maximum design shear = 386 Kips.

Using A.A.S.H.O. H20-S16 loading.

Maximum design moments = 2710 Kip-Feet.

Maximum design shear = 160 Kips.

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