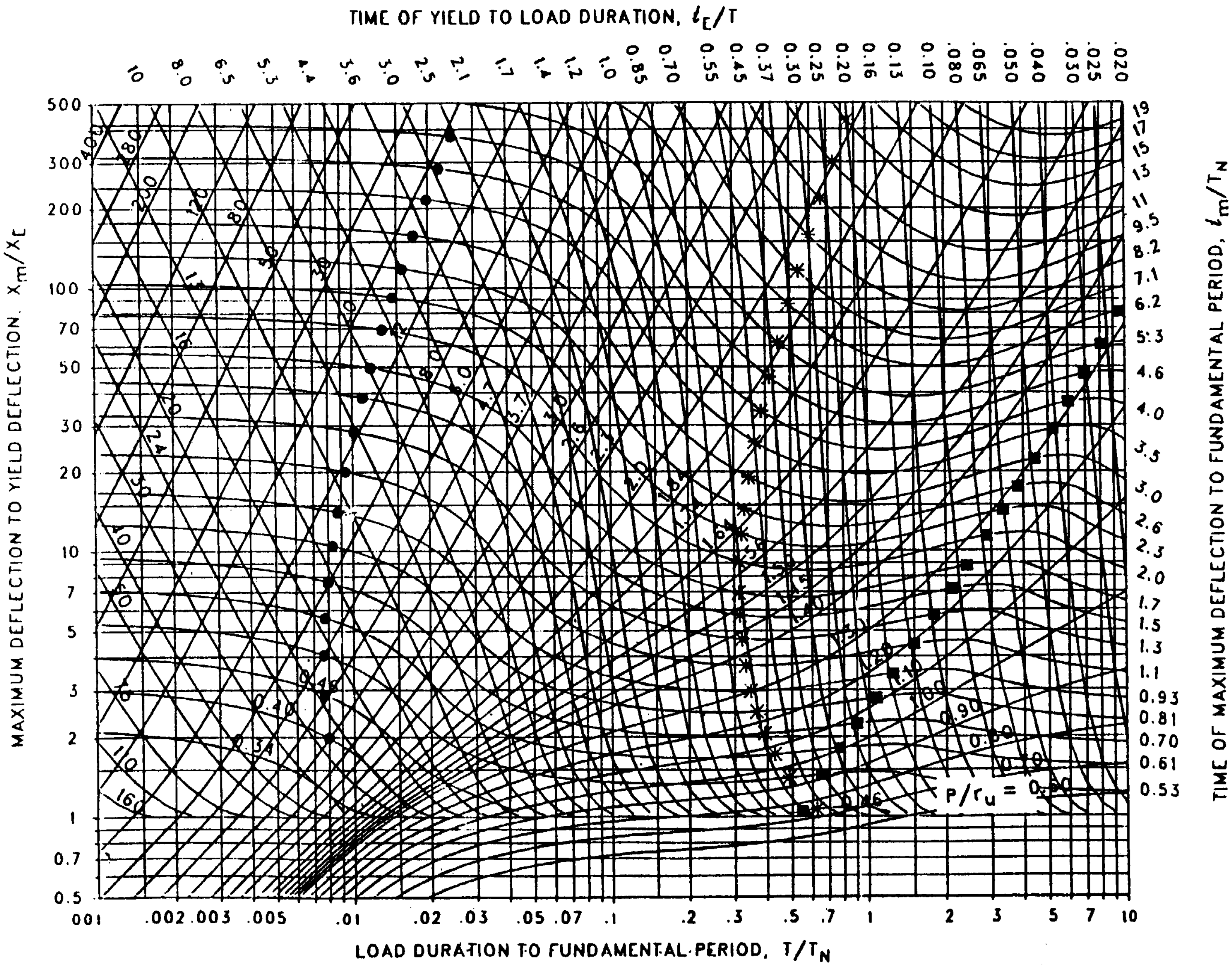


Figure 3-120 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.648, C_2 = 30)

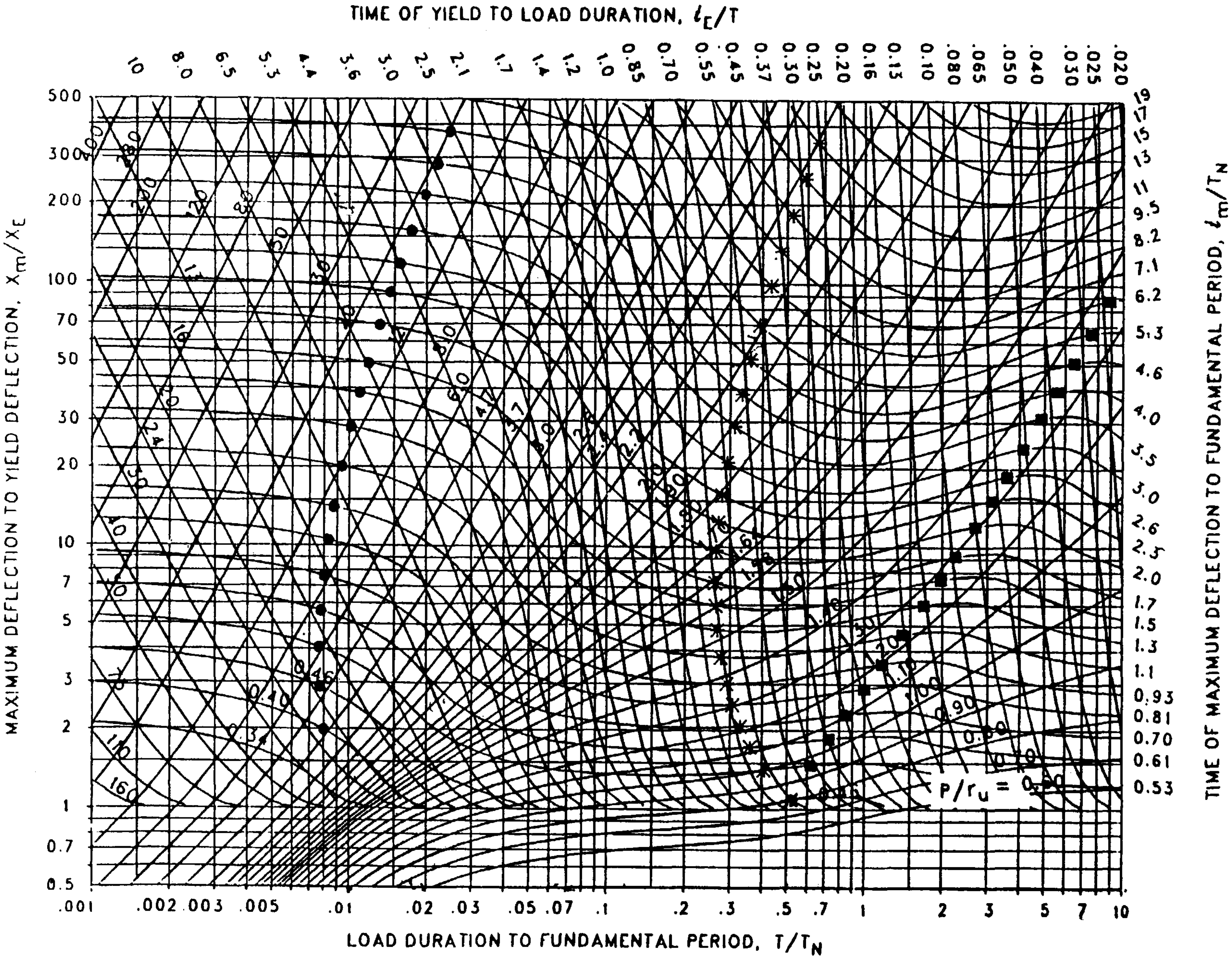


Figure 3-121 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.619, C_2 = 30)

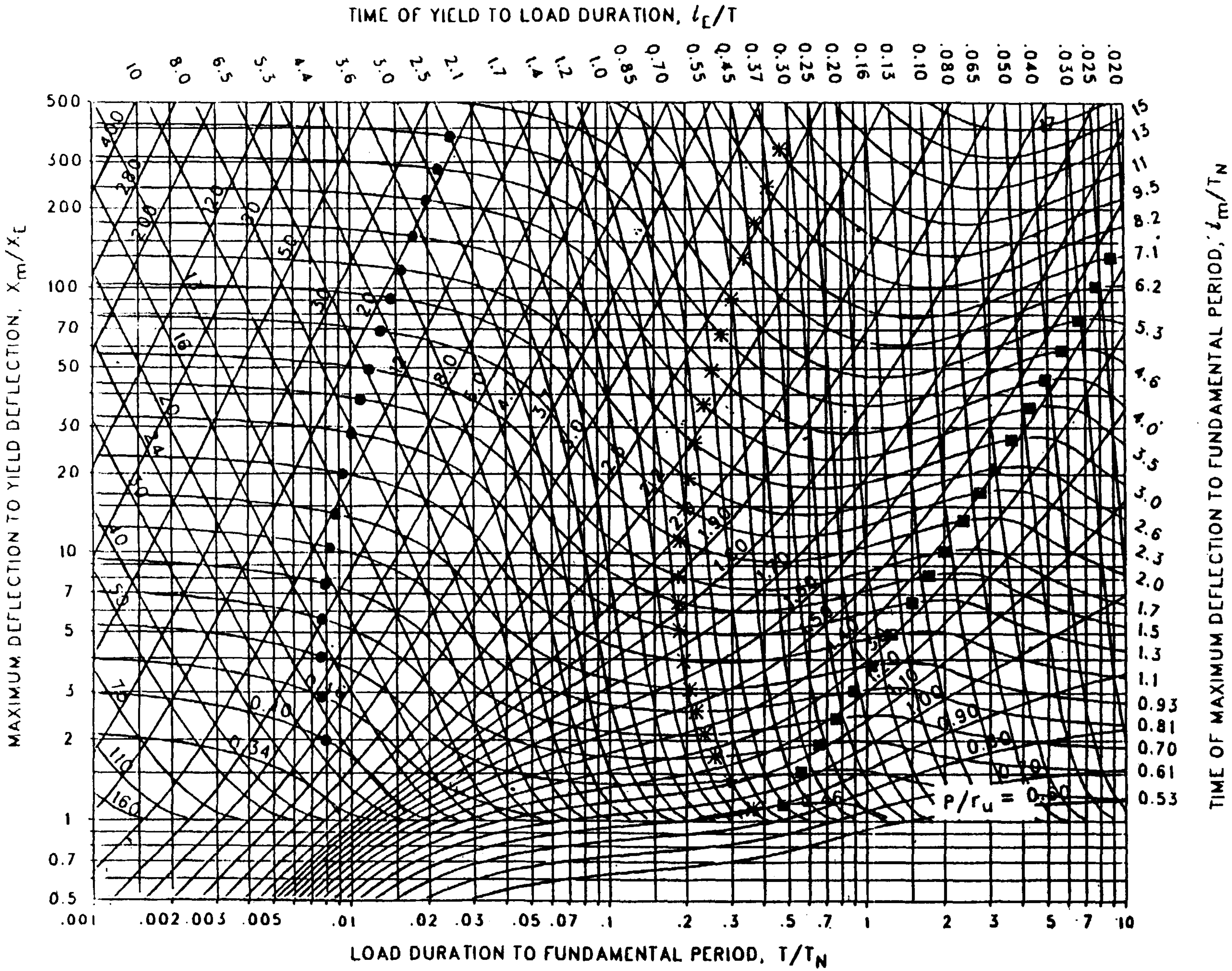


Figure 3-122 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.562, C_2 = 30)

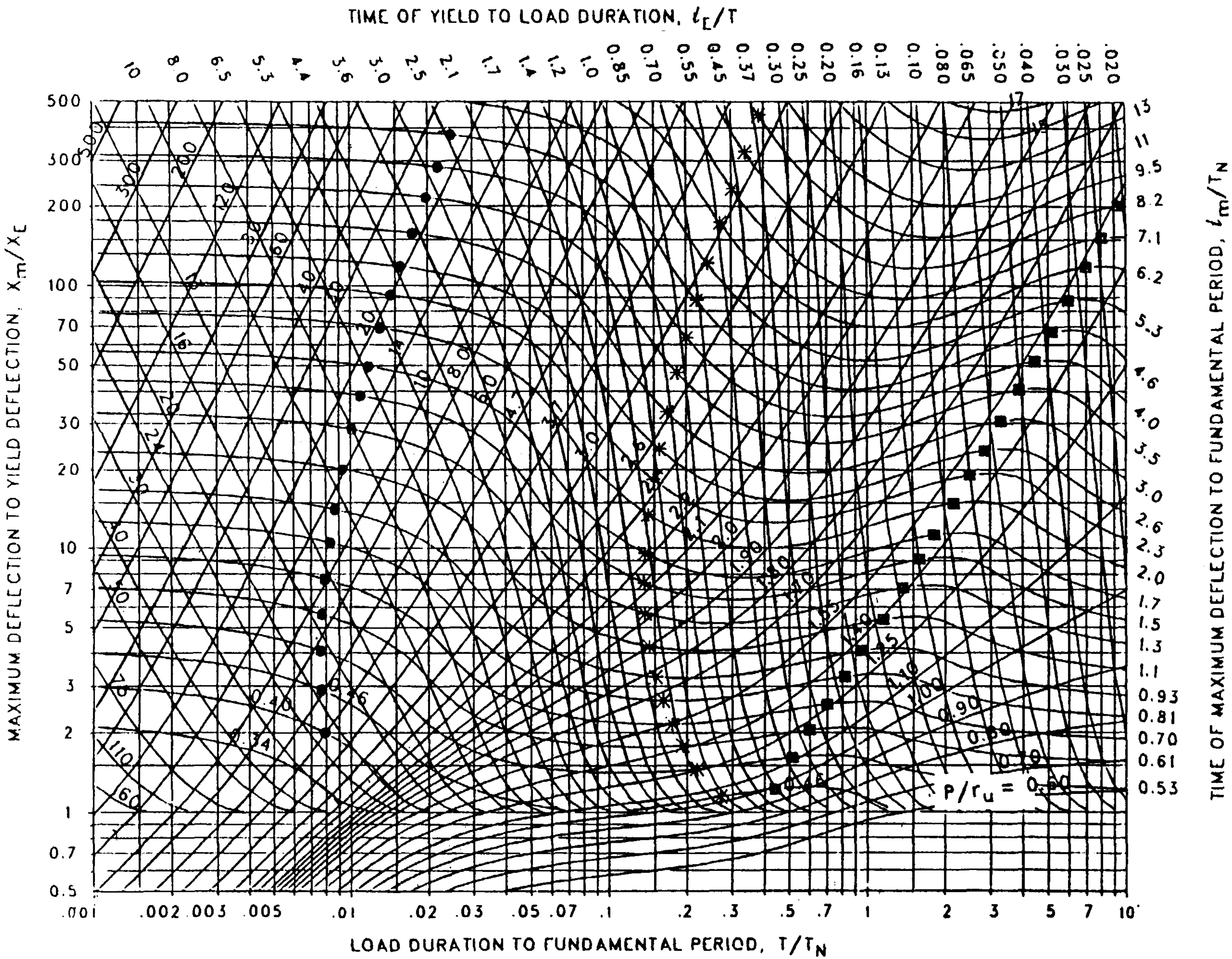


Figure 3-123 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.511, C_2 = 30)

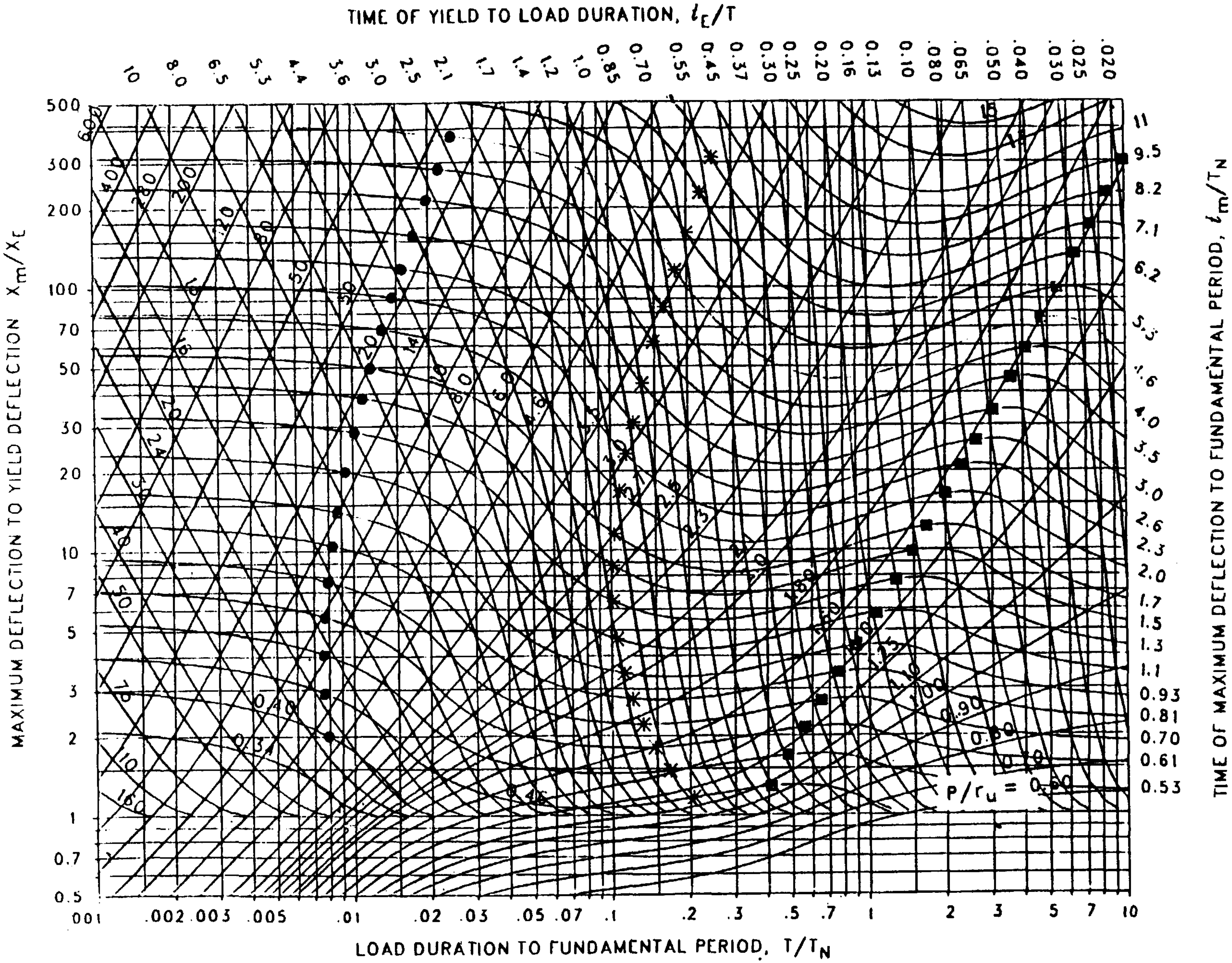


Figure 3-124 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.464, C_2 = 30)

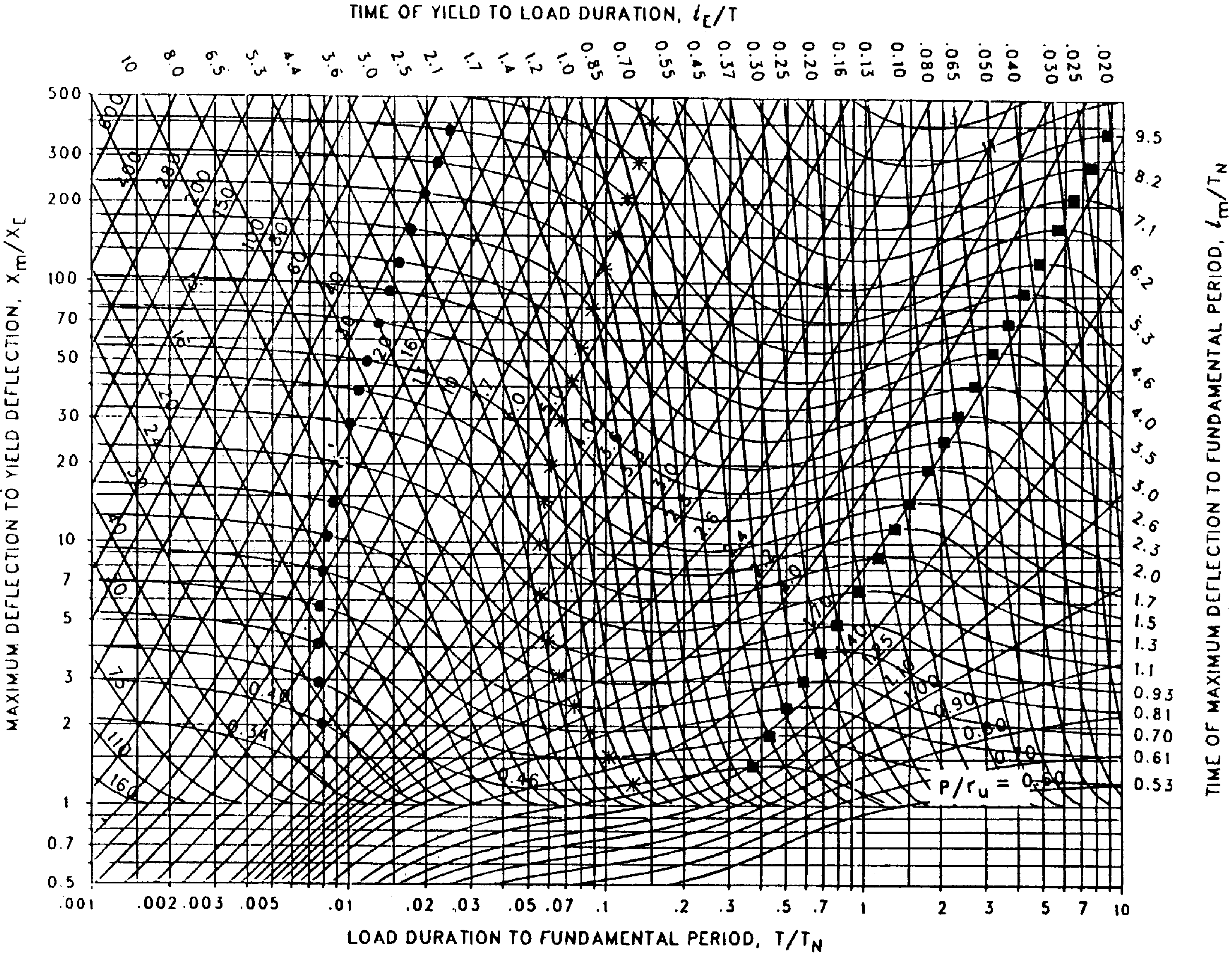


Figure 3-125 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.383, C_2 = 30)

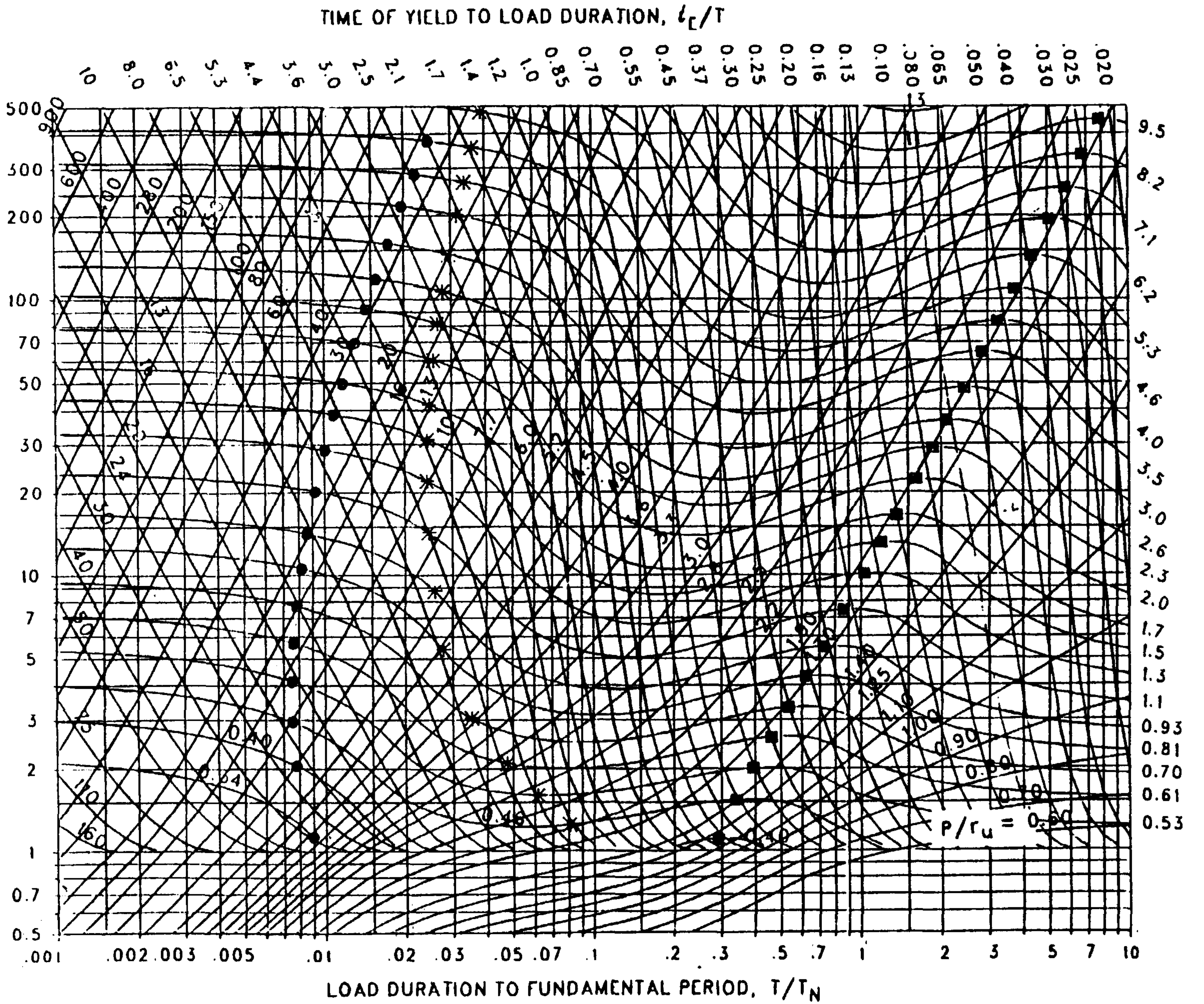


Figure 3-126 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.316, C_2 = 30)

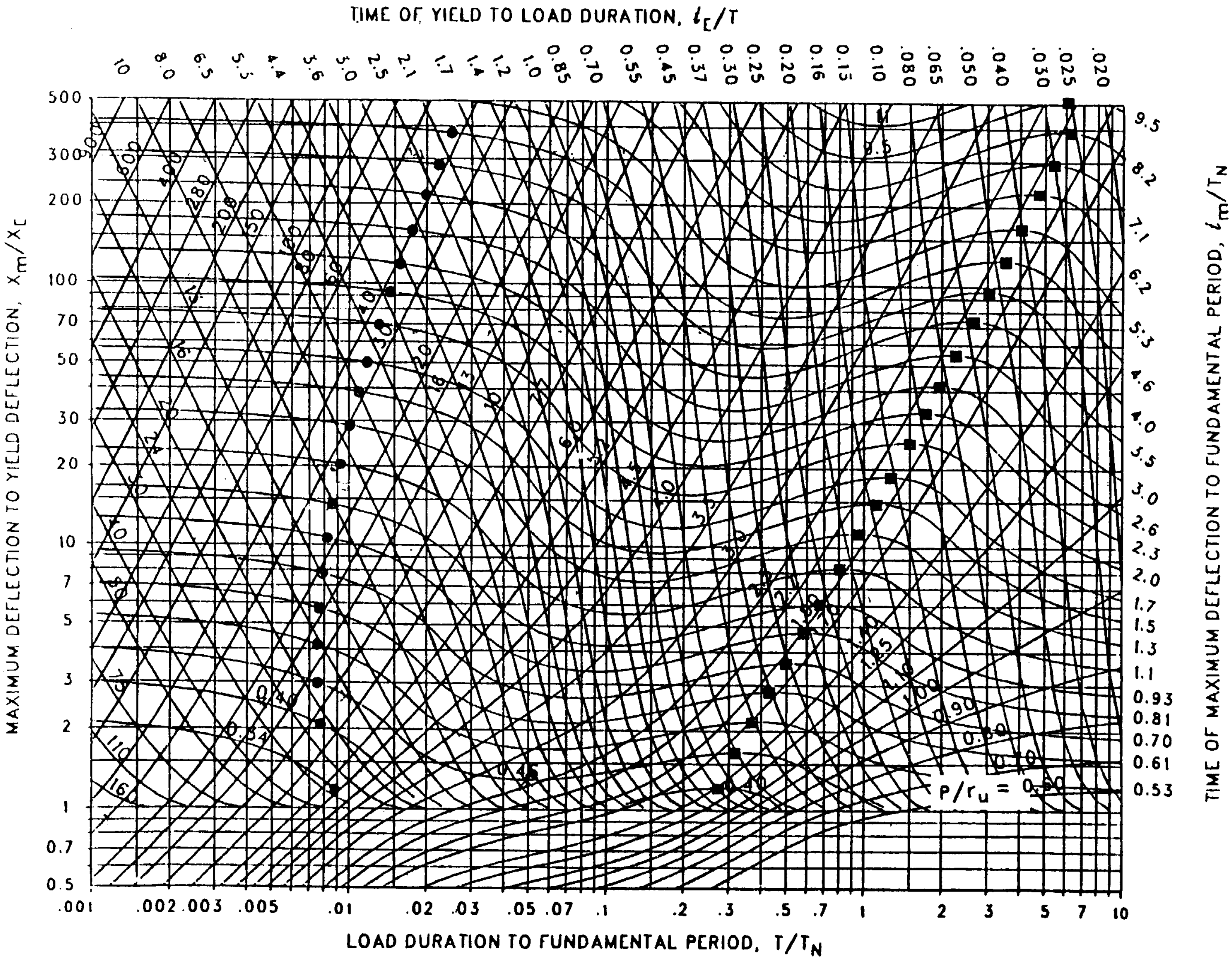


Figure 3-127 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.261, C_2 = 30)

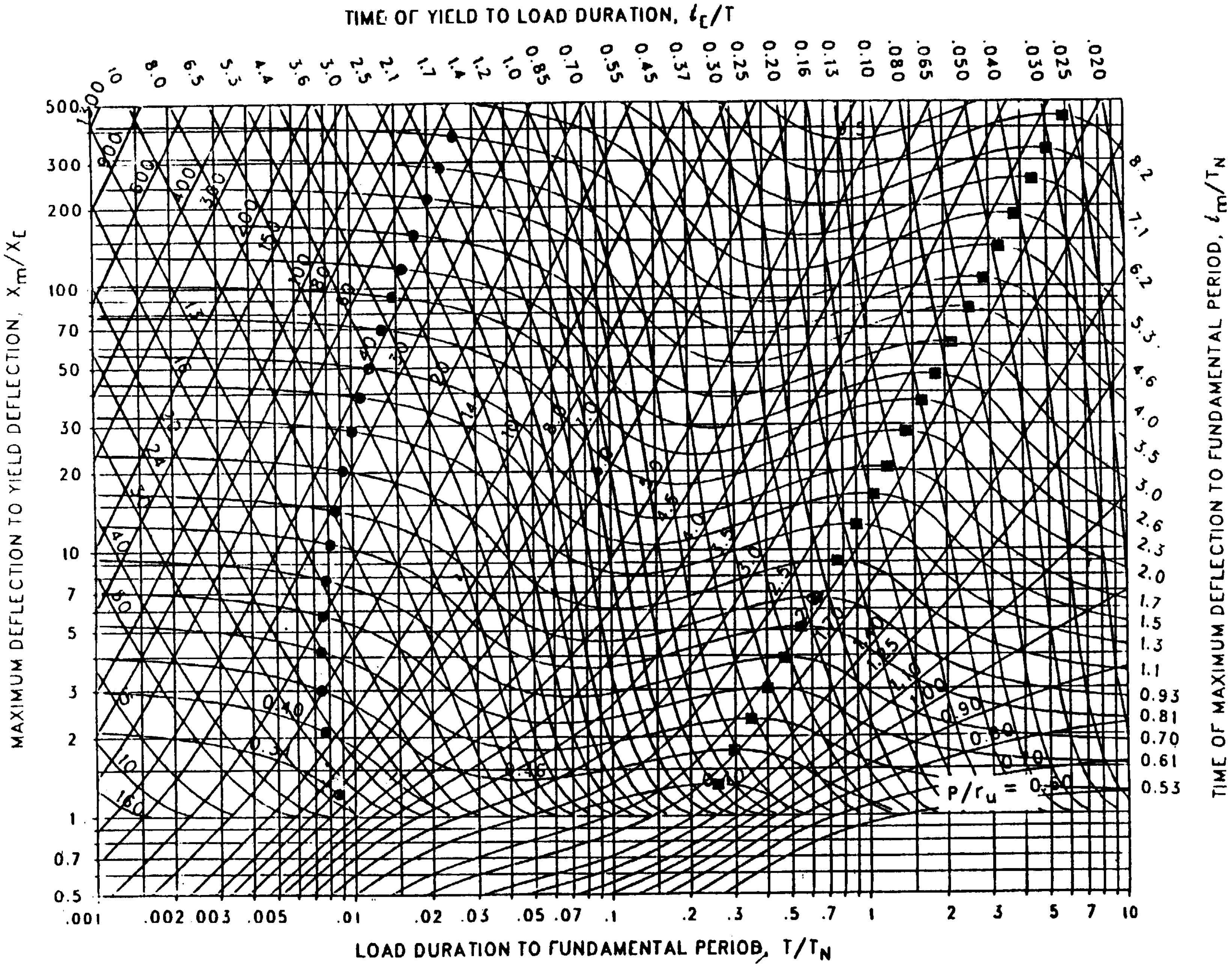


Figure 3-128 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.215, C_2 = 30)

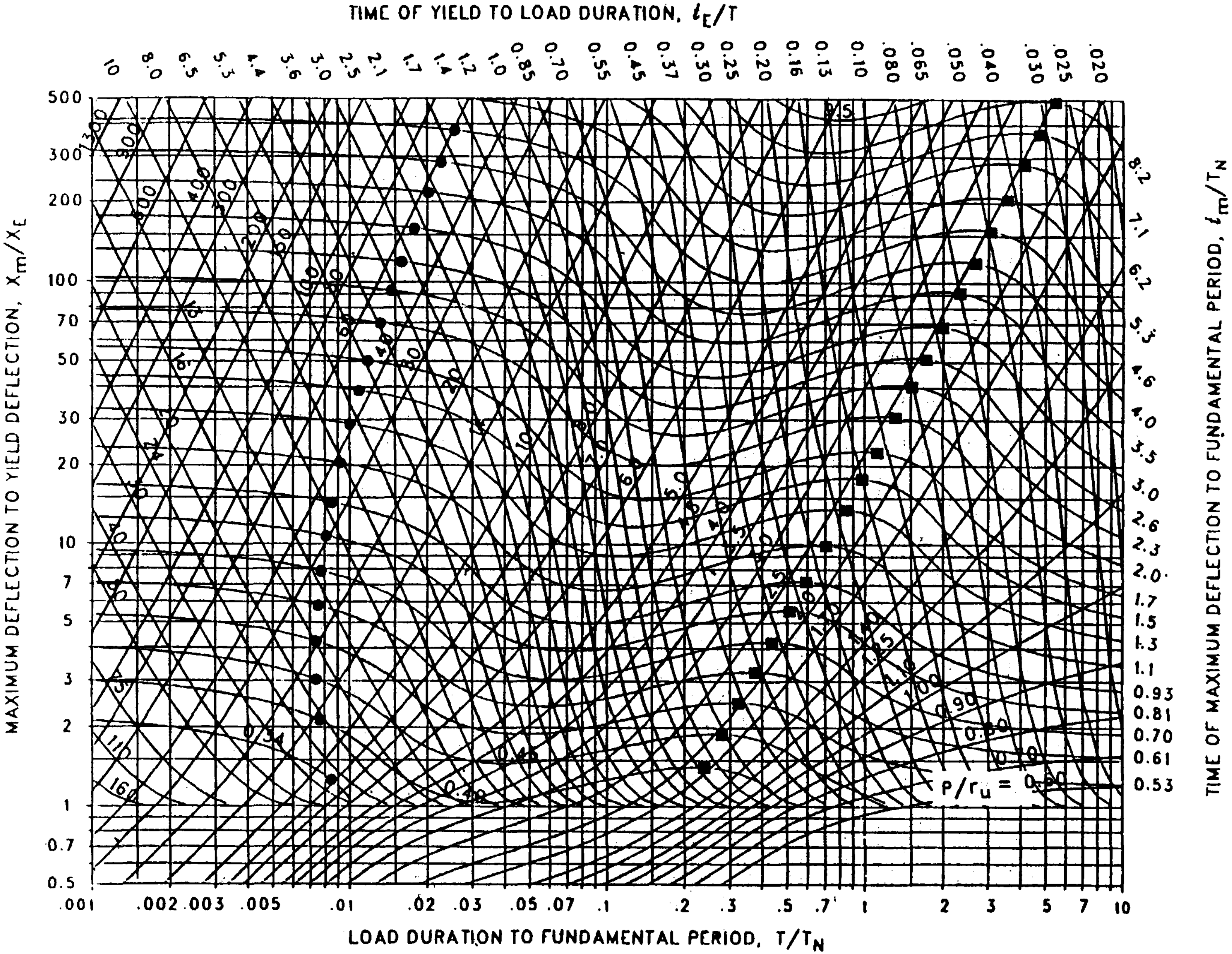


Figure 3-129 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.178, C_2 = 30)

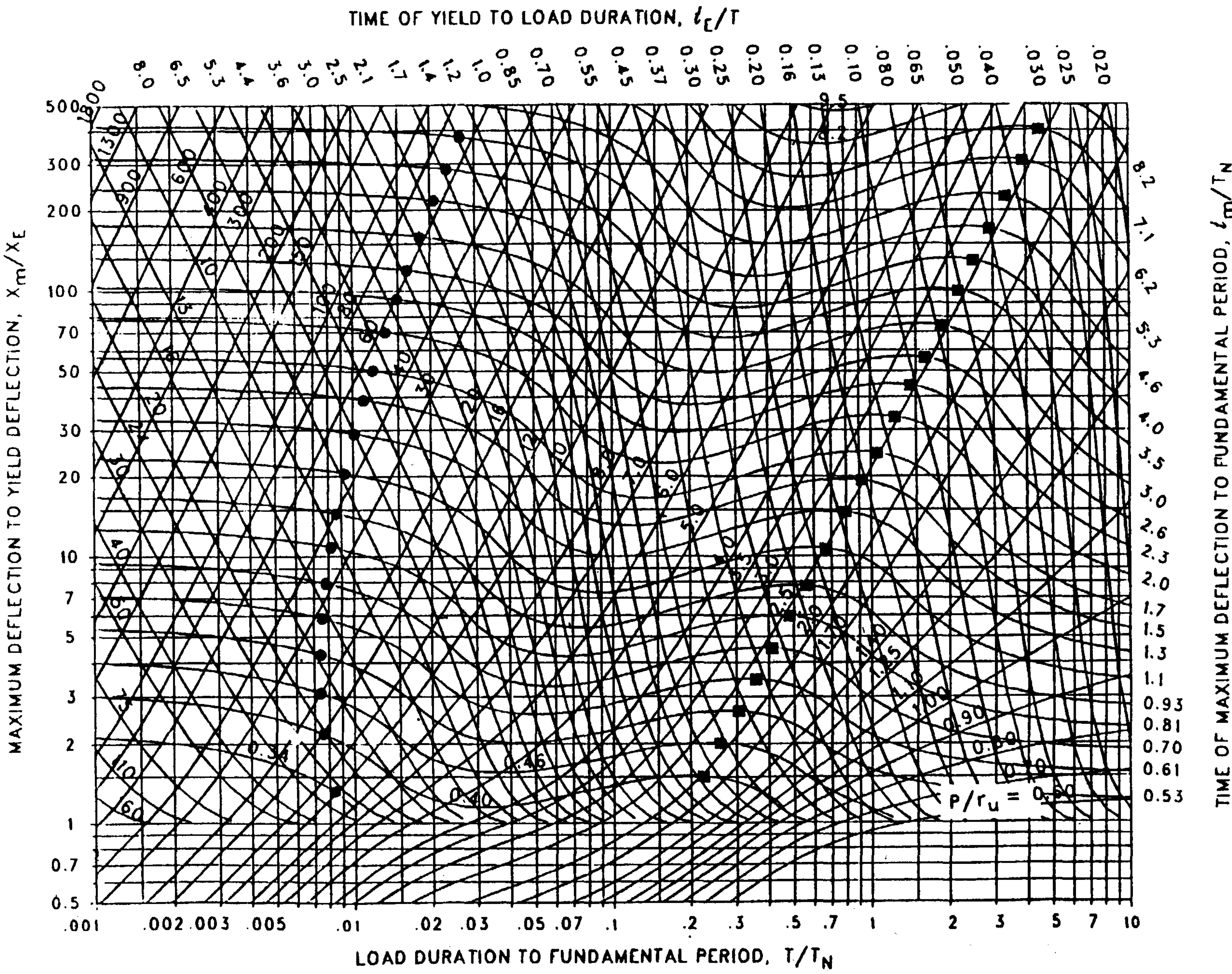


Figure 3-130 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.147, C_2 = 30)

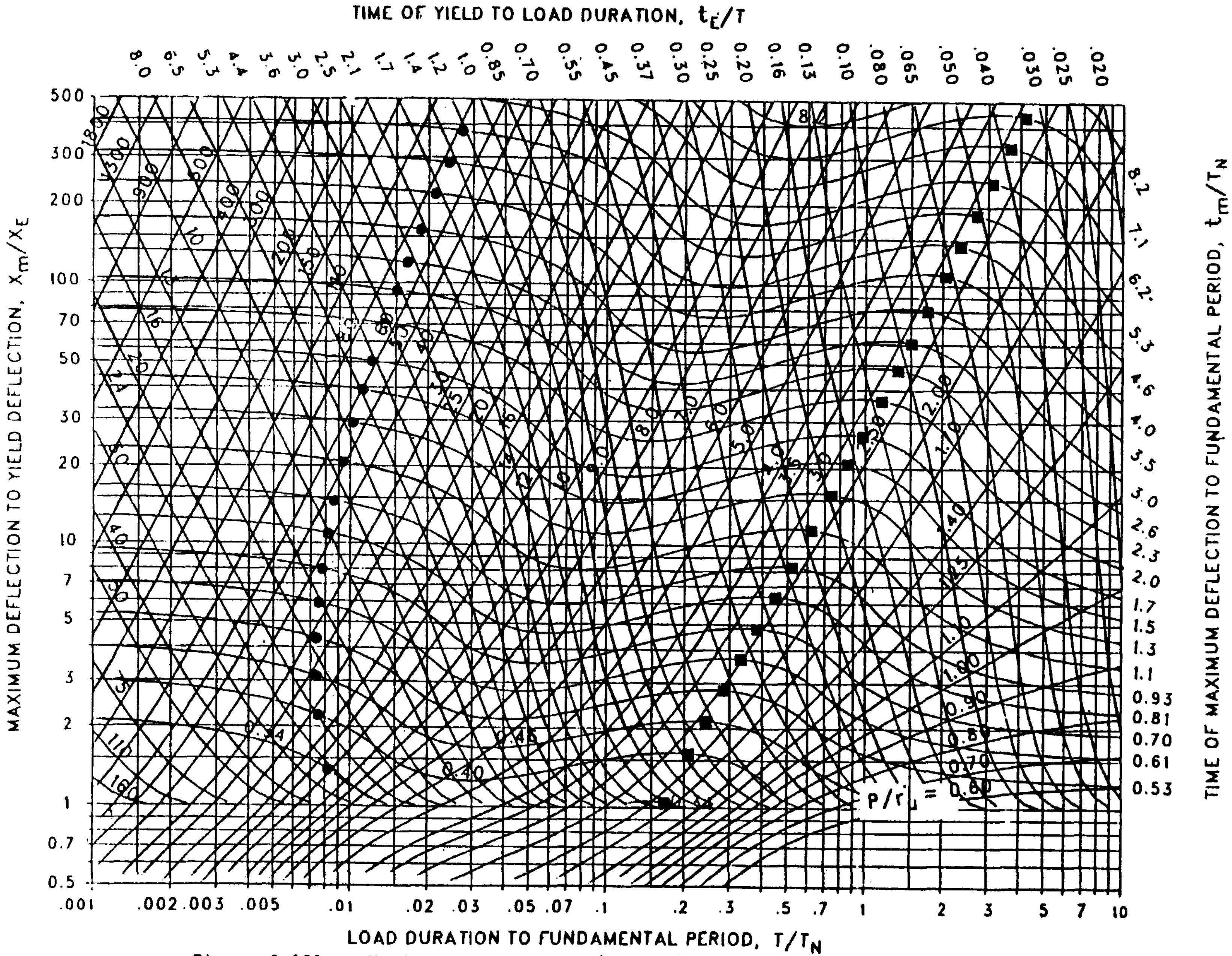


Figure 3-131 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.121, C_2 = 30)

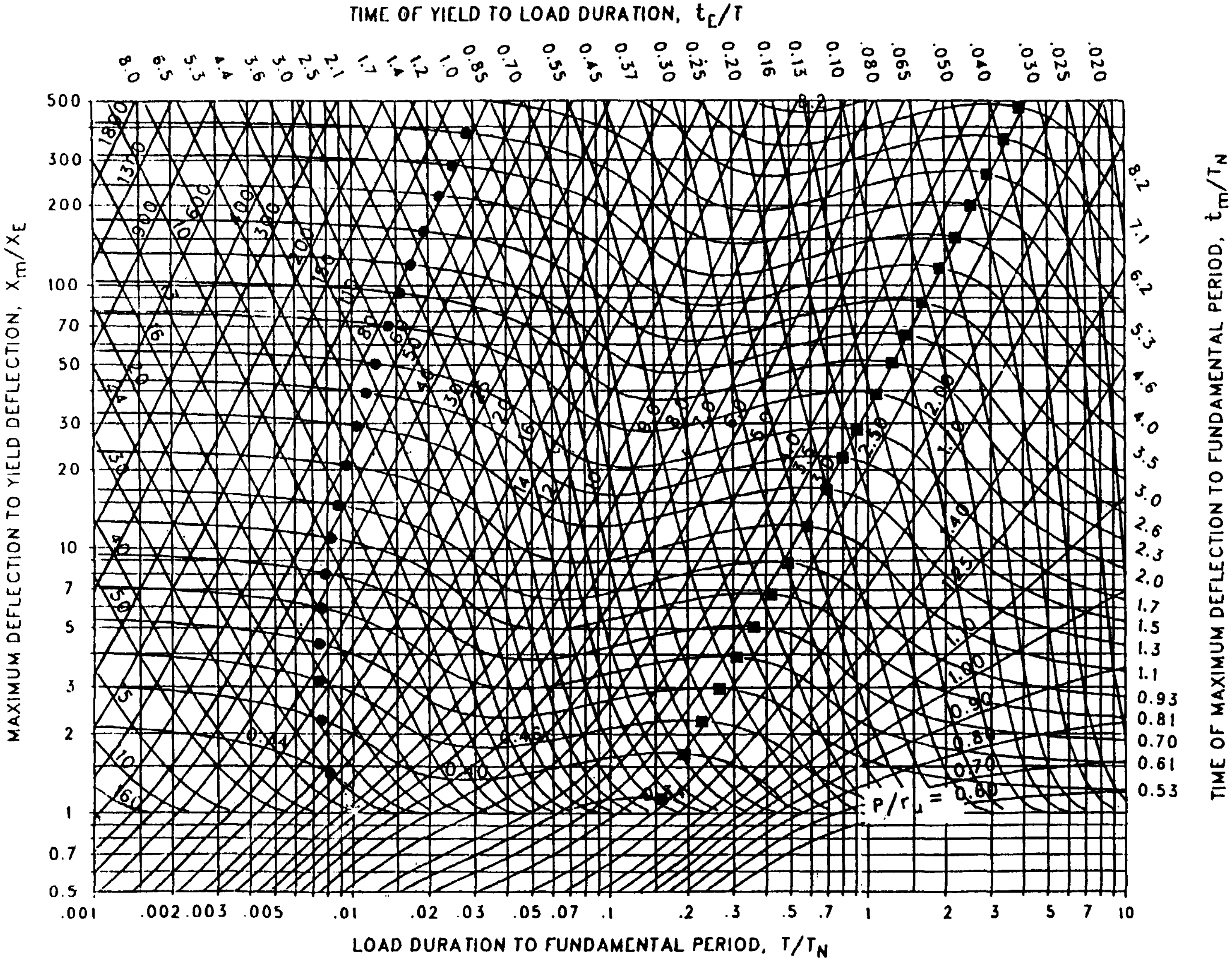


Figure 3-132 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.100, C_2 = 30)

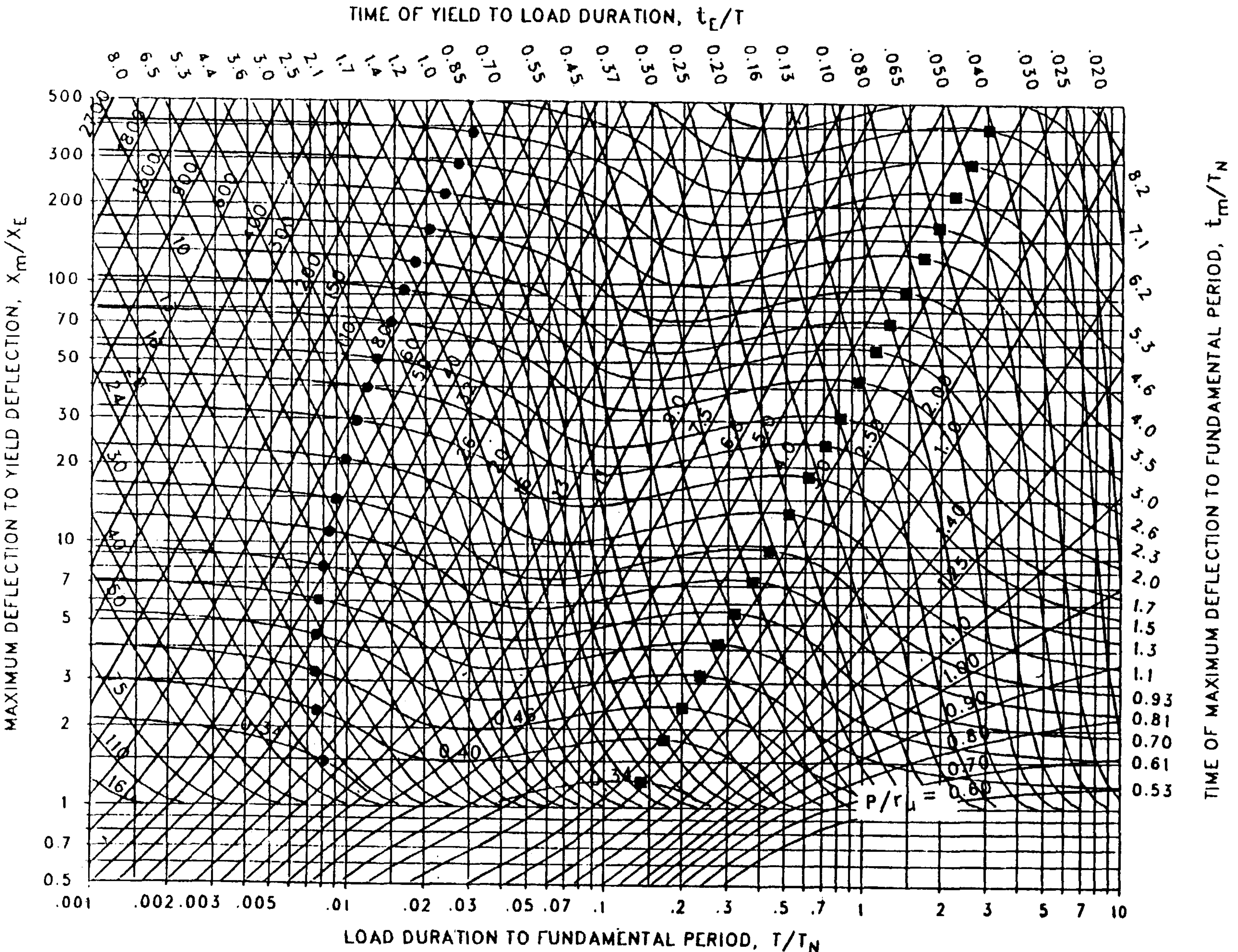


Figure 3-133 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.075, C_2 = 30)

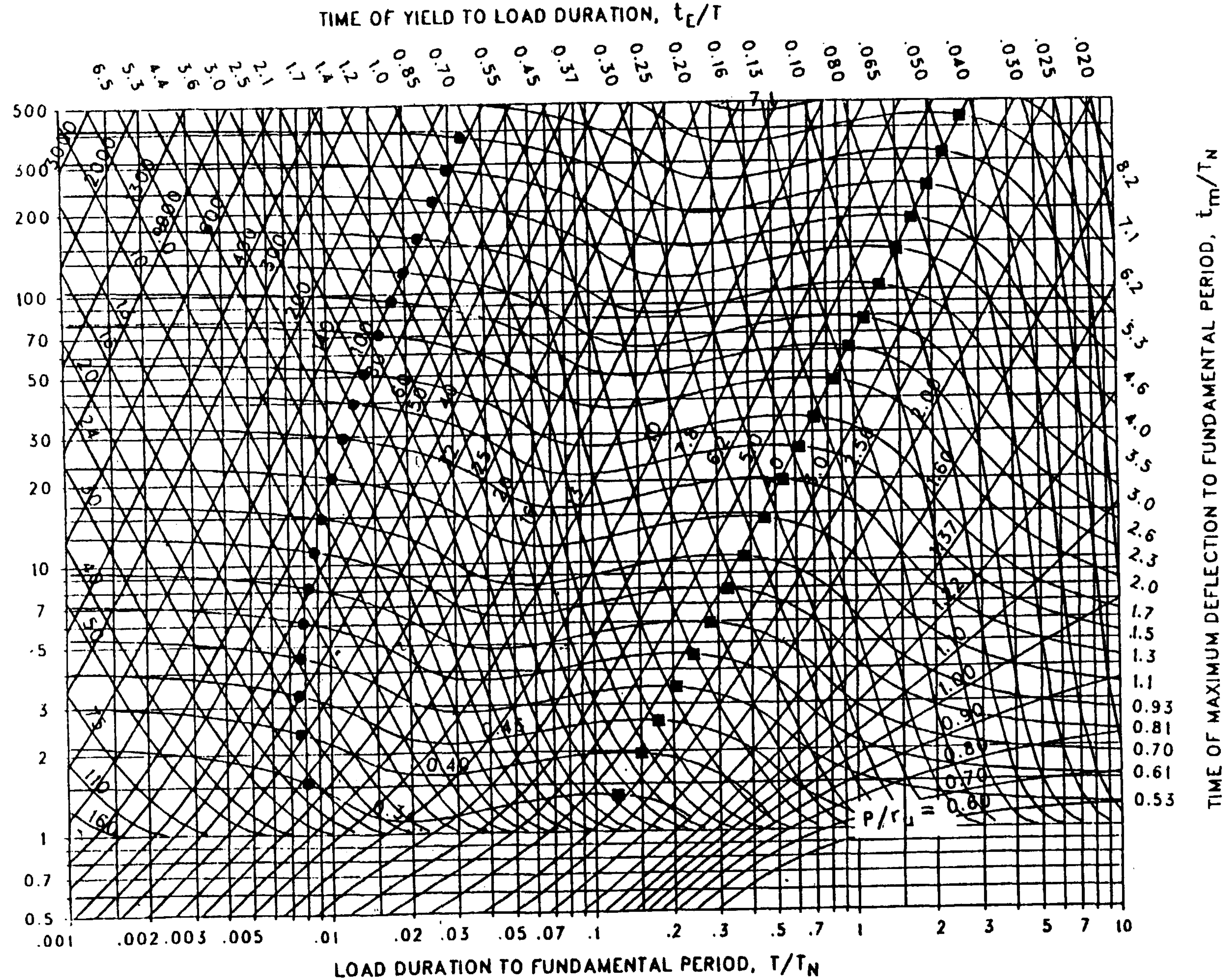


Figure 3-134 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.056, C_2 = 30)

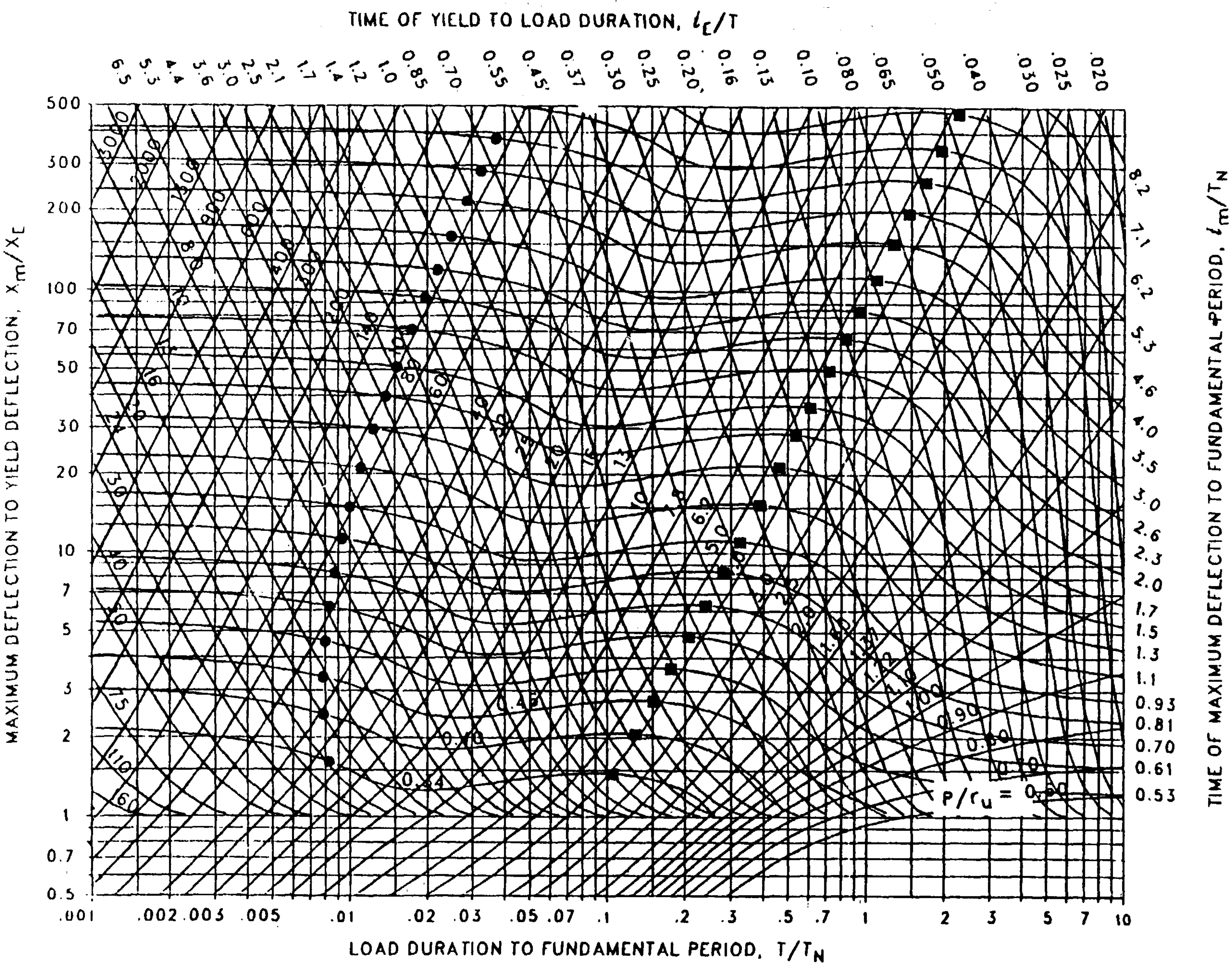


Figure 3-135 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.042, C_2 = 30)

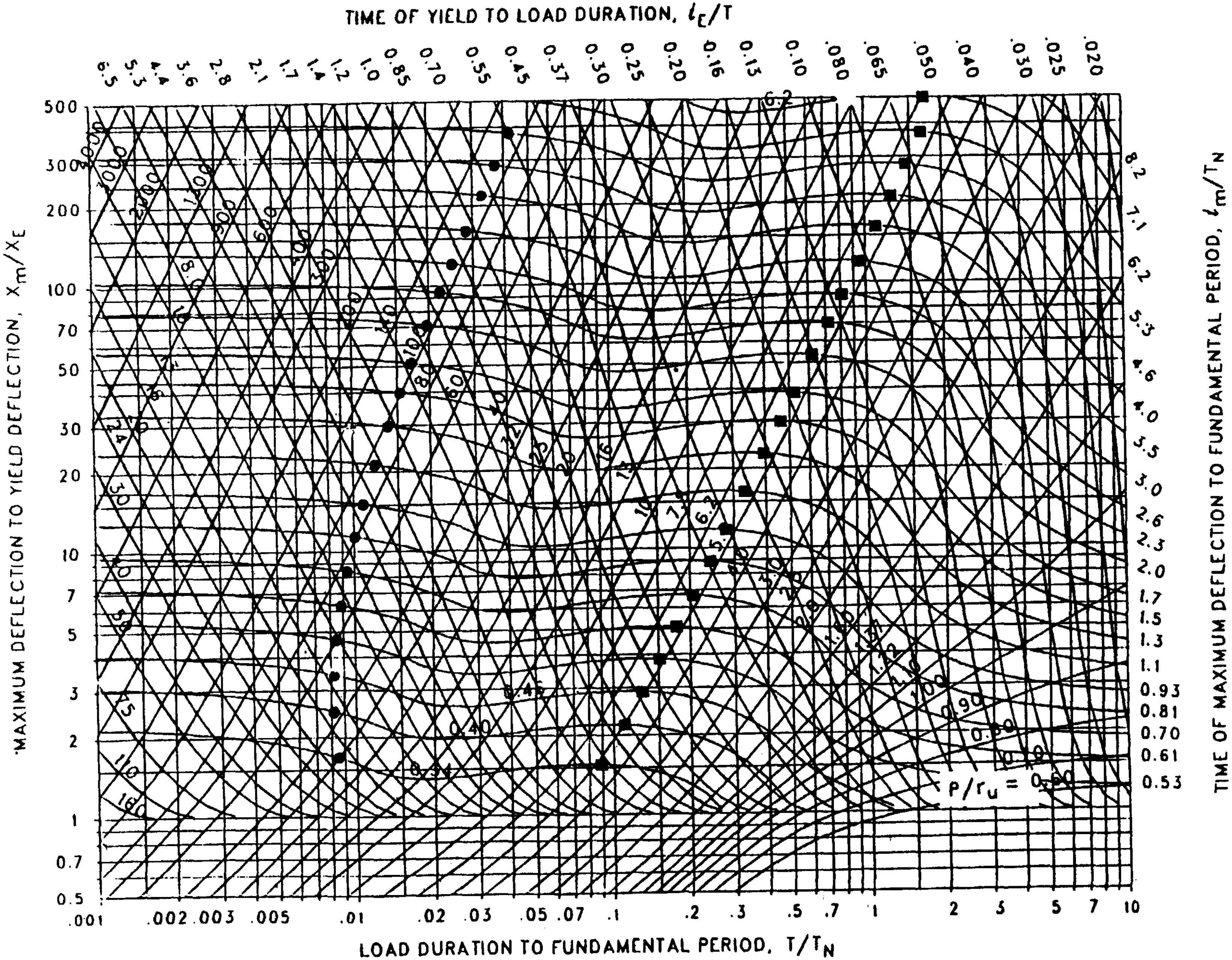


Figure 3-136 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.032, C_2 = 30)

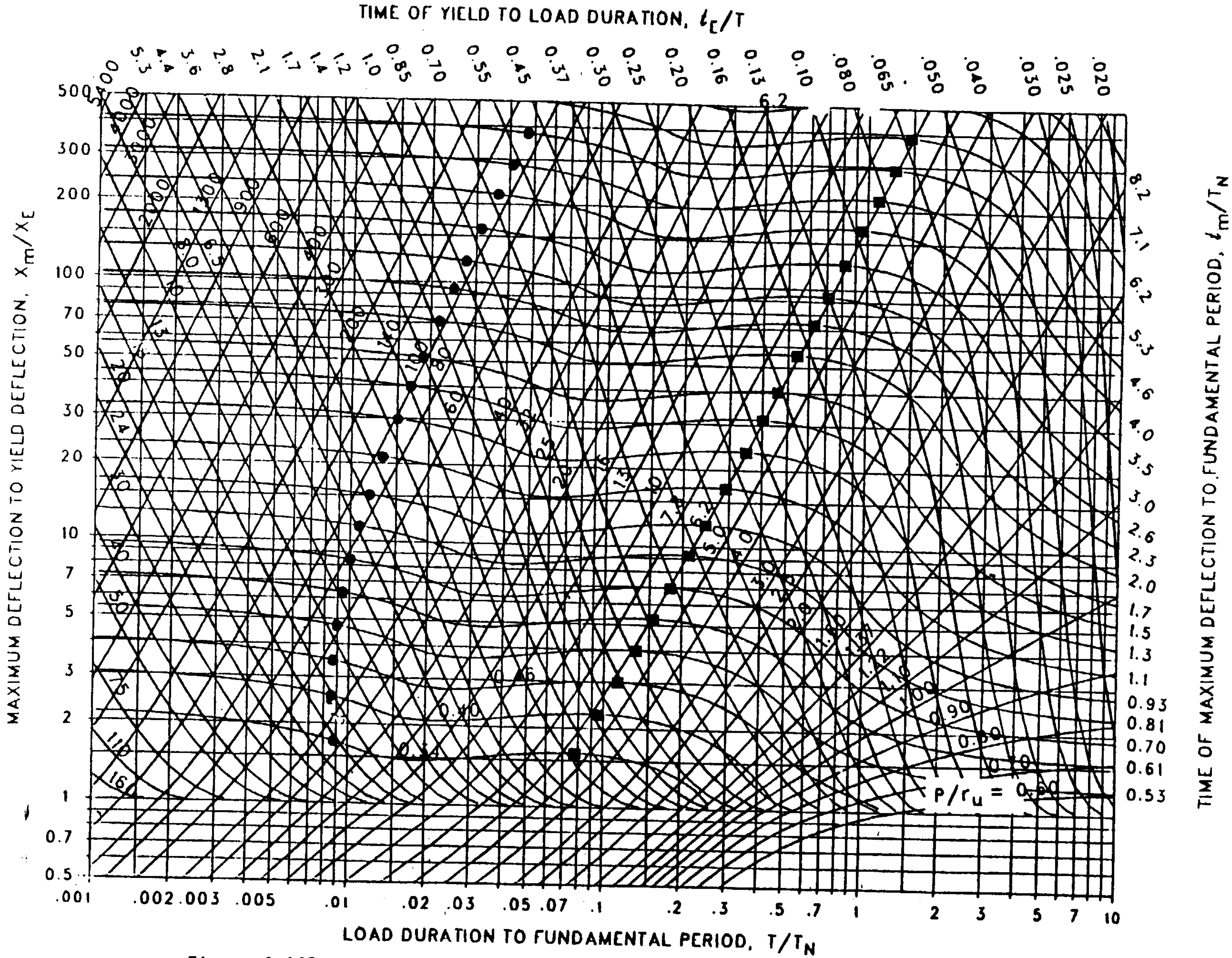


Figure 3-137 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.026, C_2 = 30)

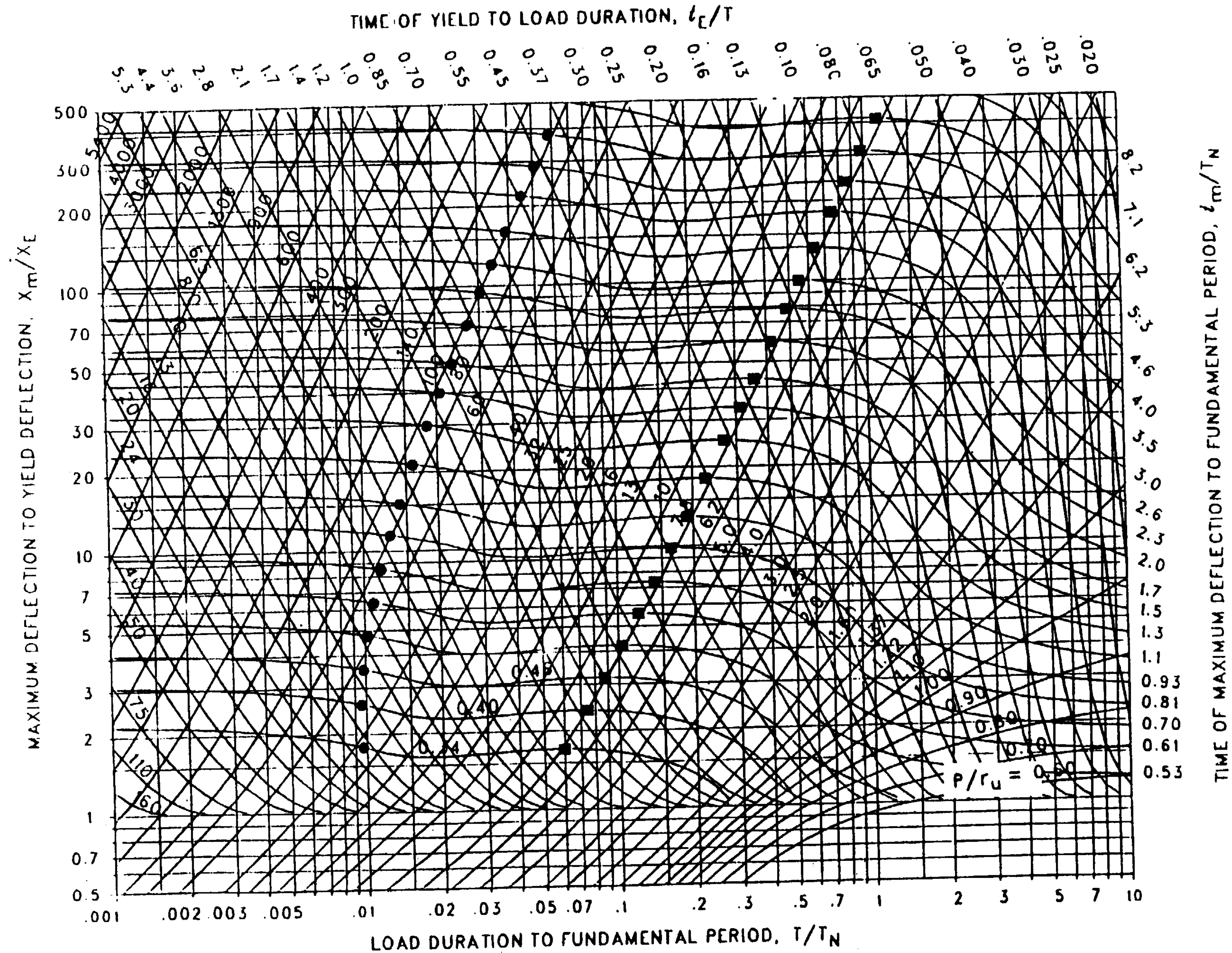


Figure 3-138 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.018, C_2 = 30)

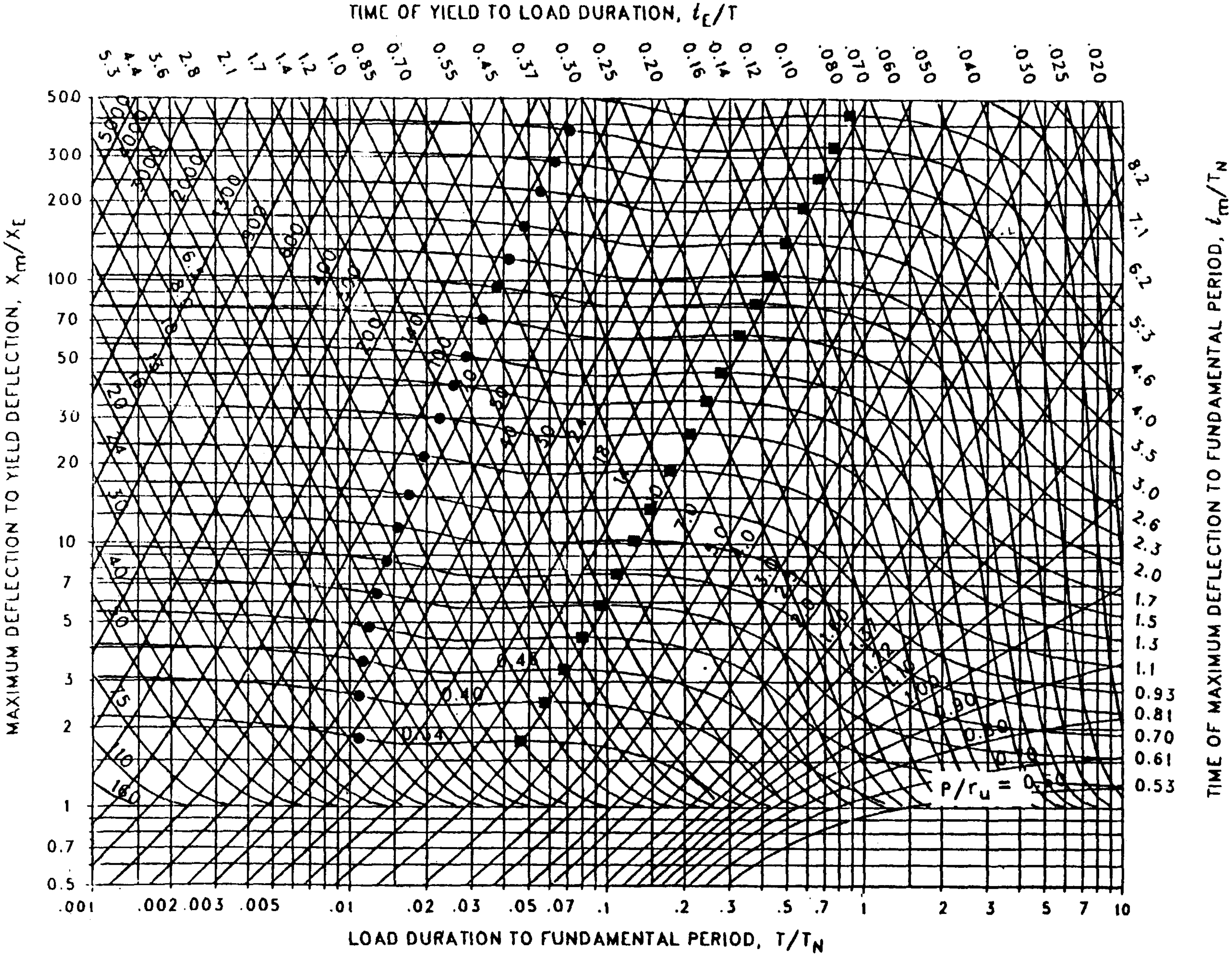


Figure 3-139 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.013, C_2 = 30)

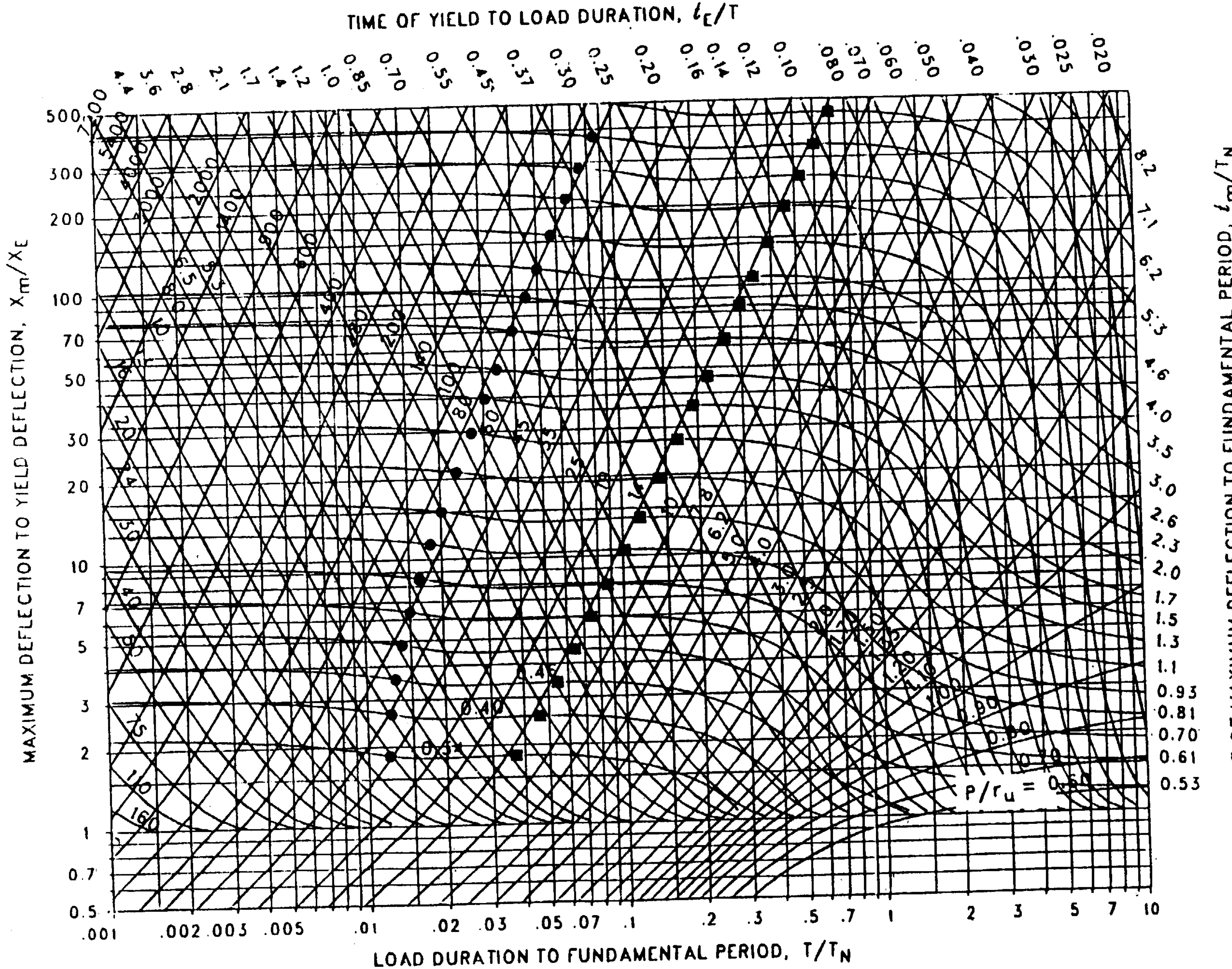


Figure 3-140 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.010, C_2 = 30)

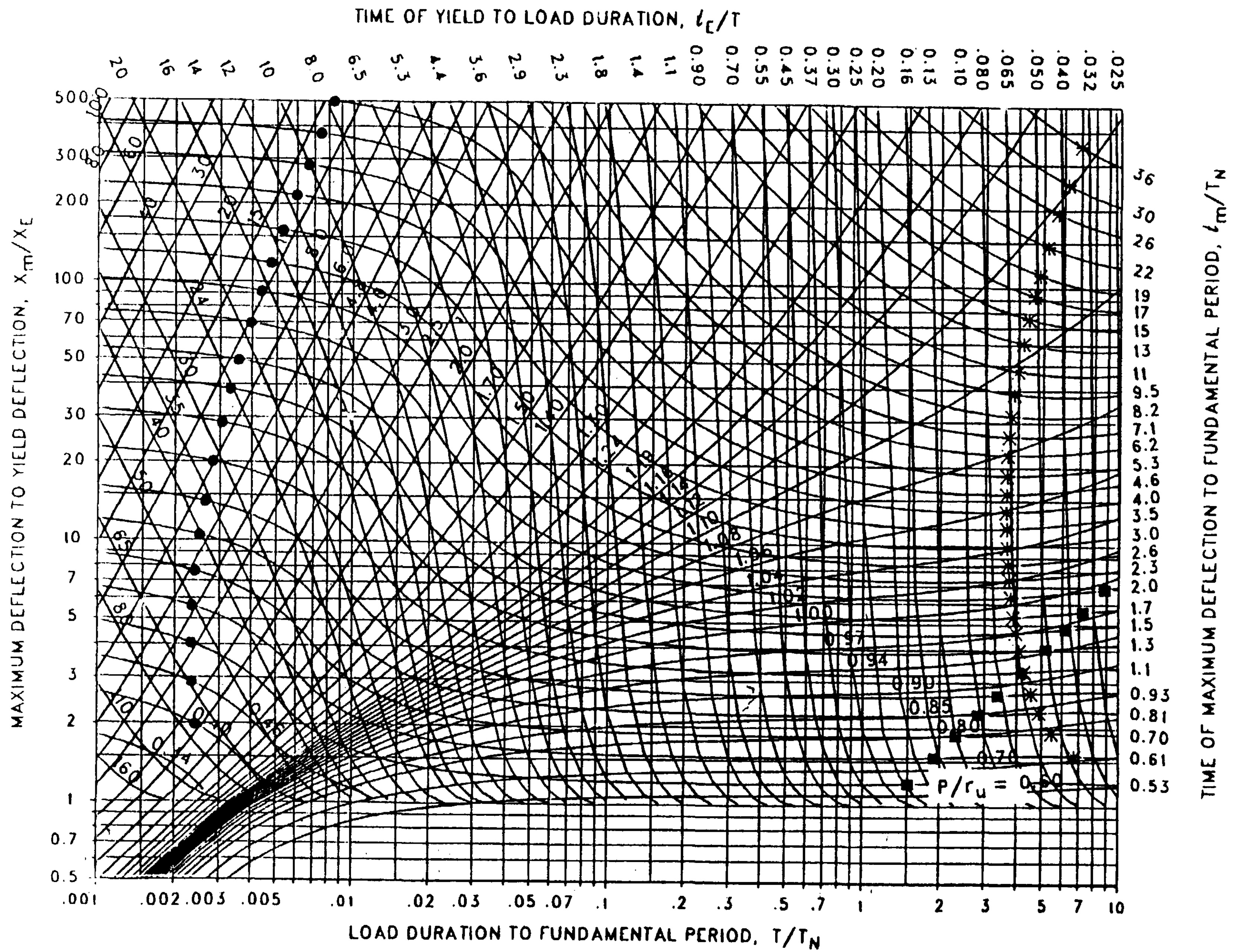


Figure 3-141 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.909, C_2 = 100.)

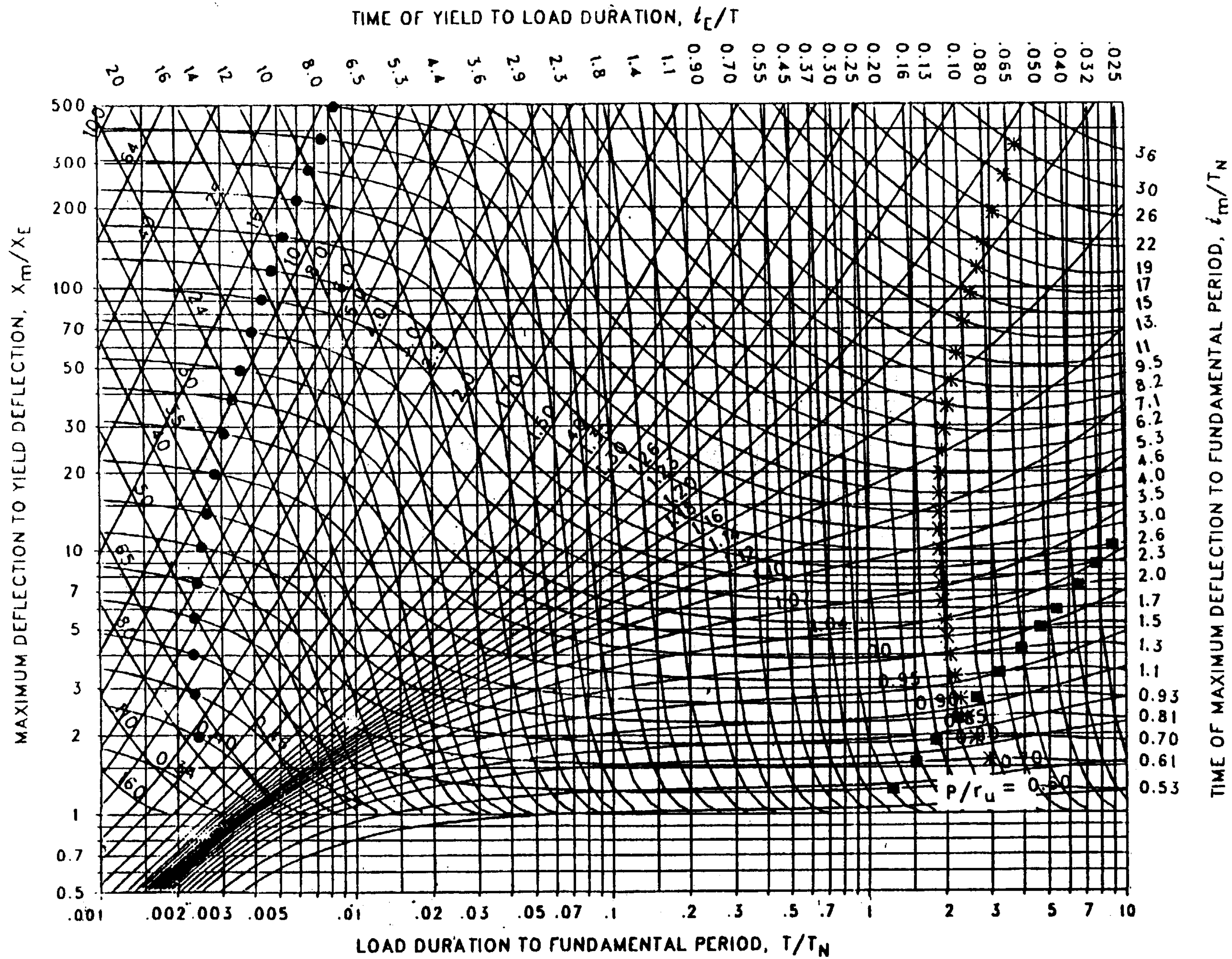


Figure 3-142 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.866, C_2 = 100.)

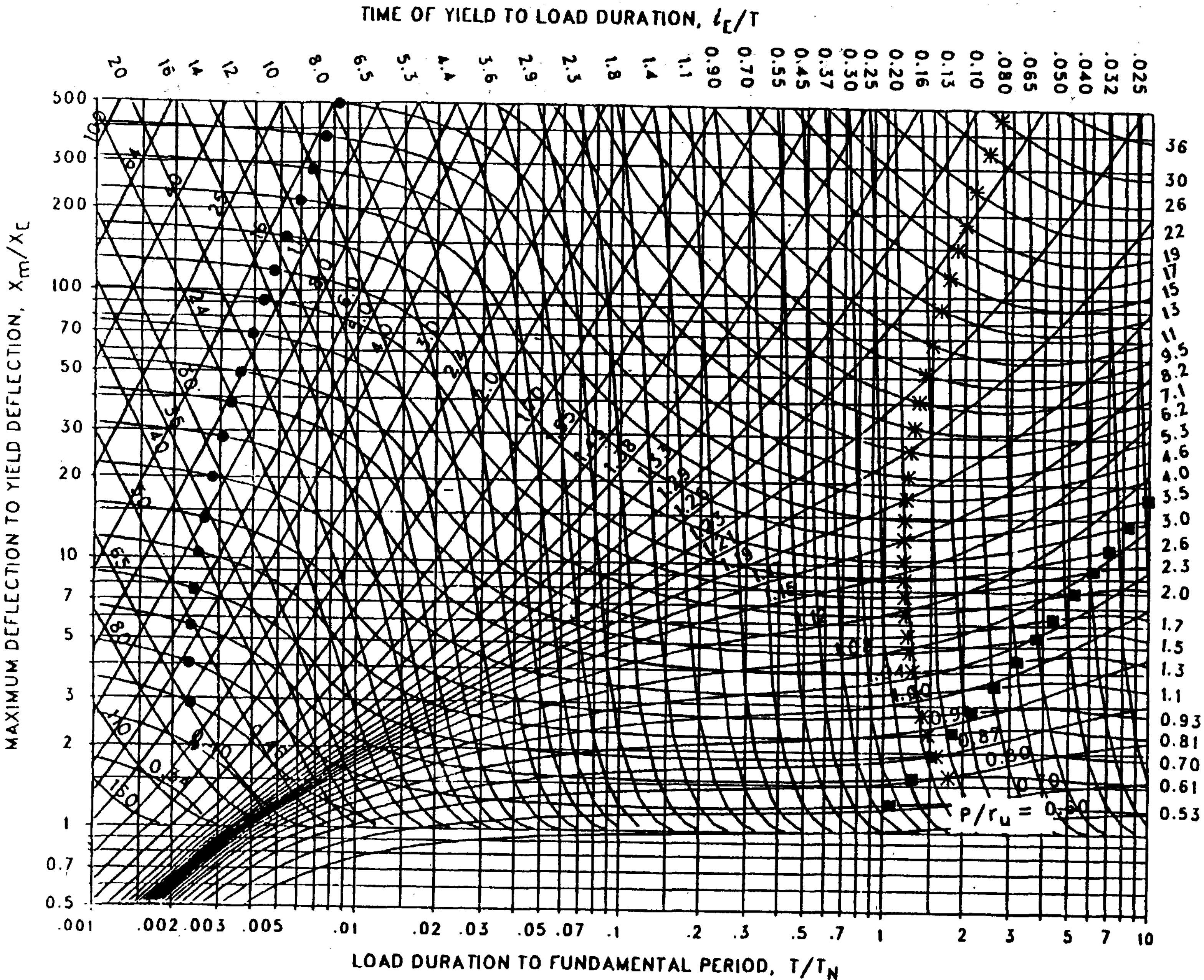


Figure 3-143 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.825, C_2 = 100.)

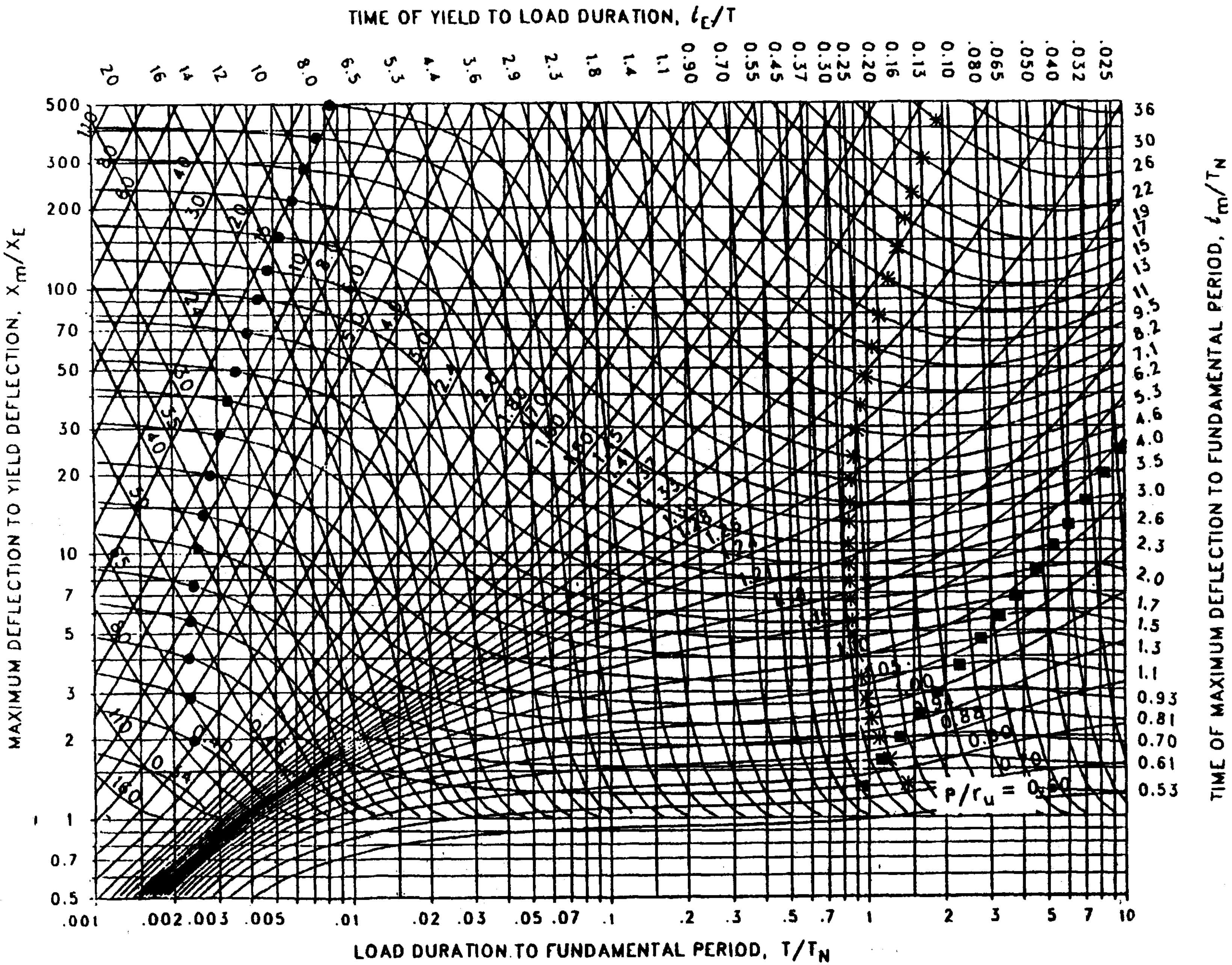


Figure 3-144 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.787, C_2 = 100.)

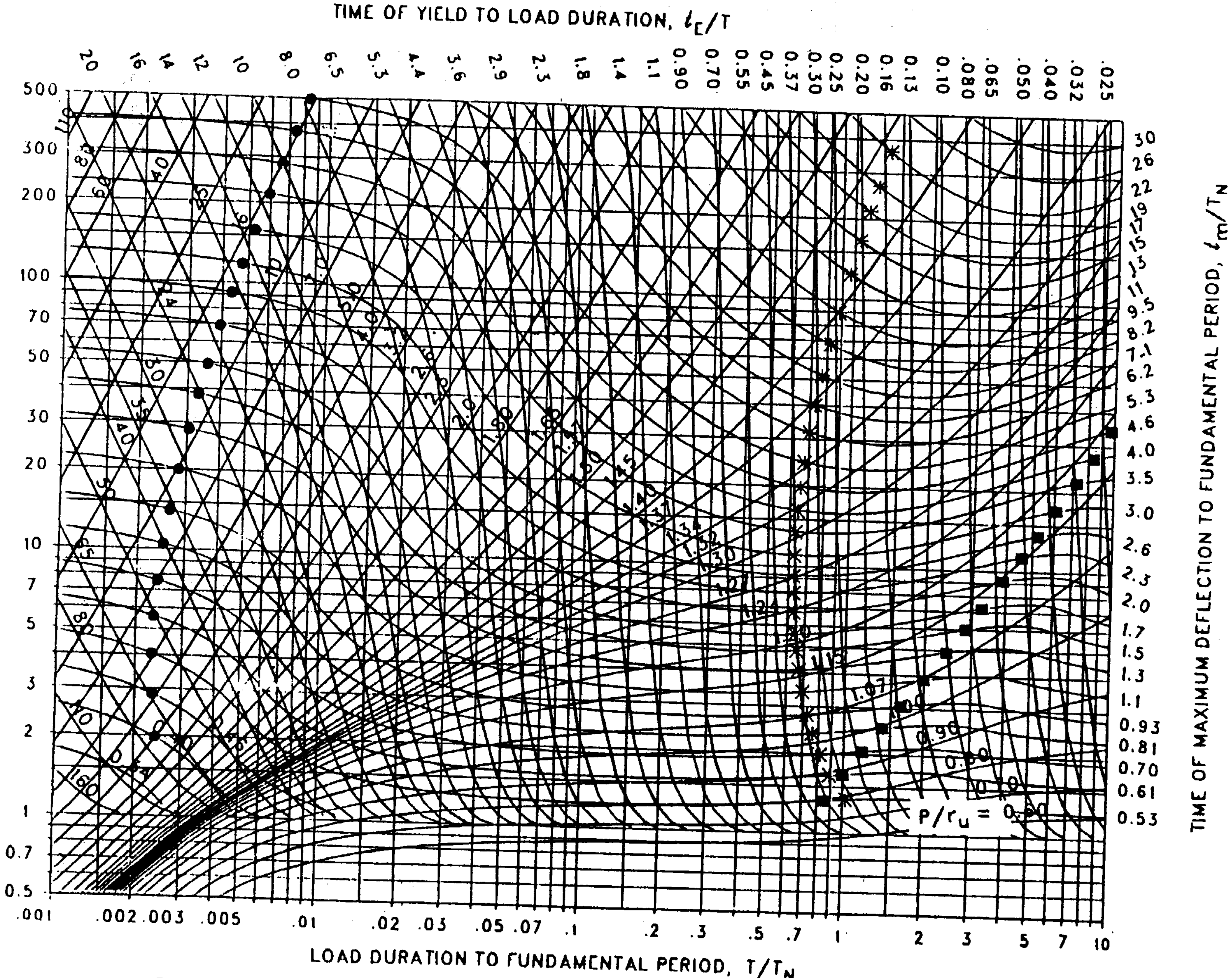


Figure 3-145 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.750, C_2 = 100.)

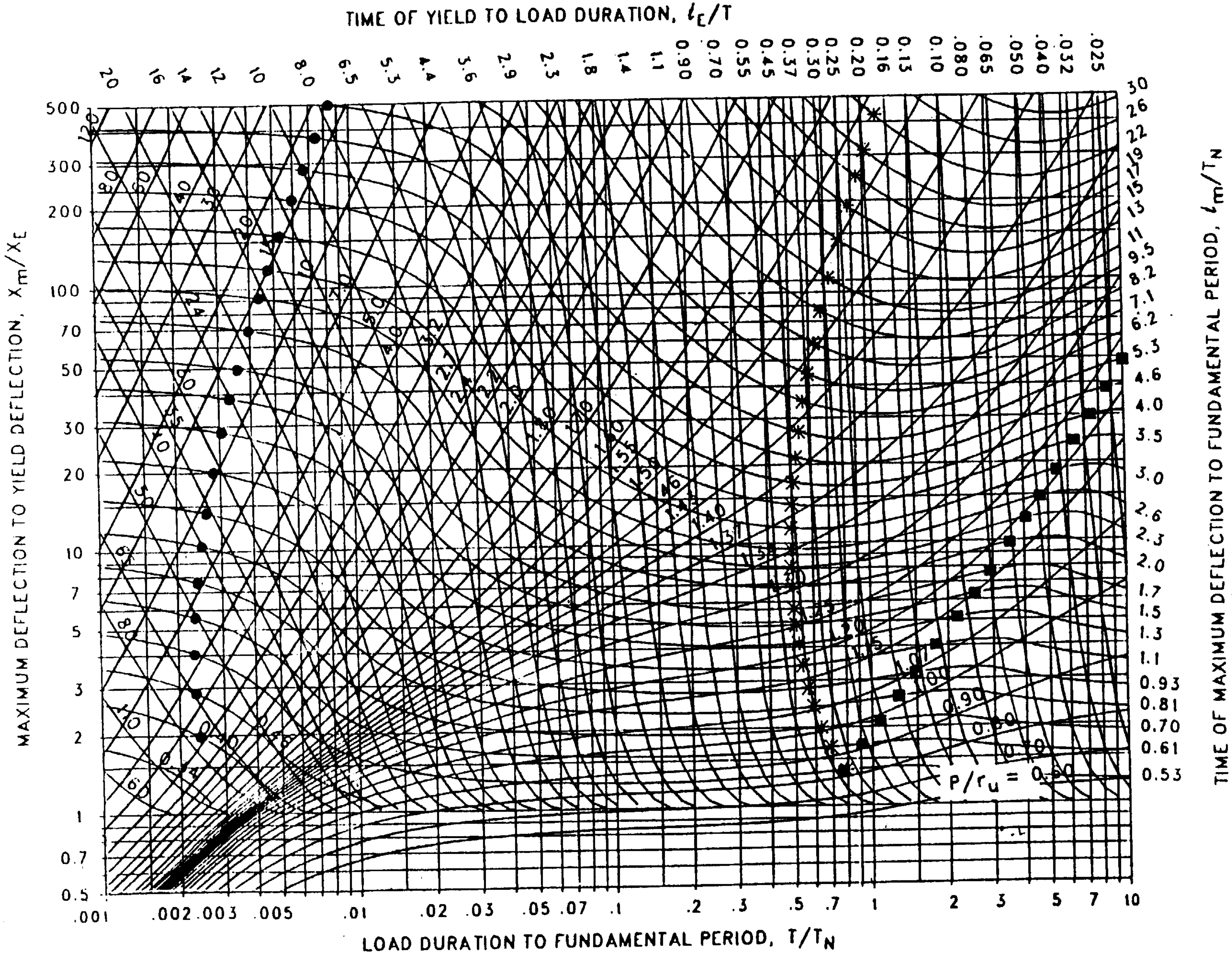


Figure 3-146 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.715, C_2 = 100.)

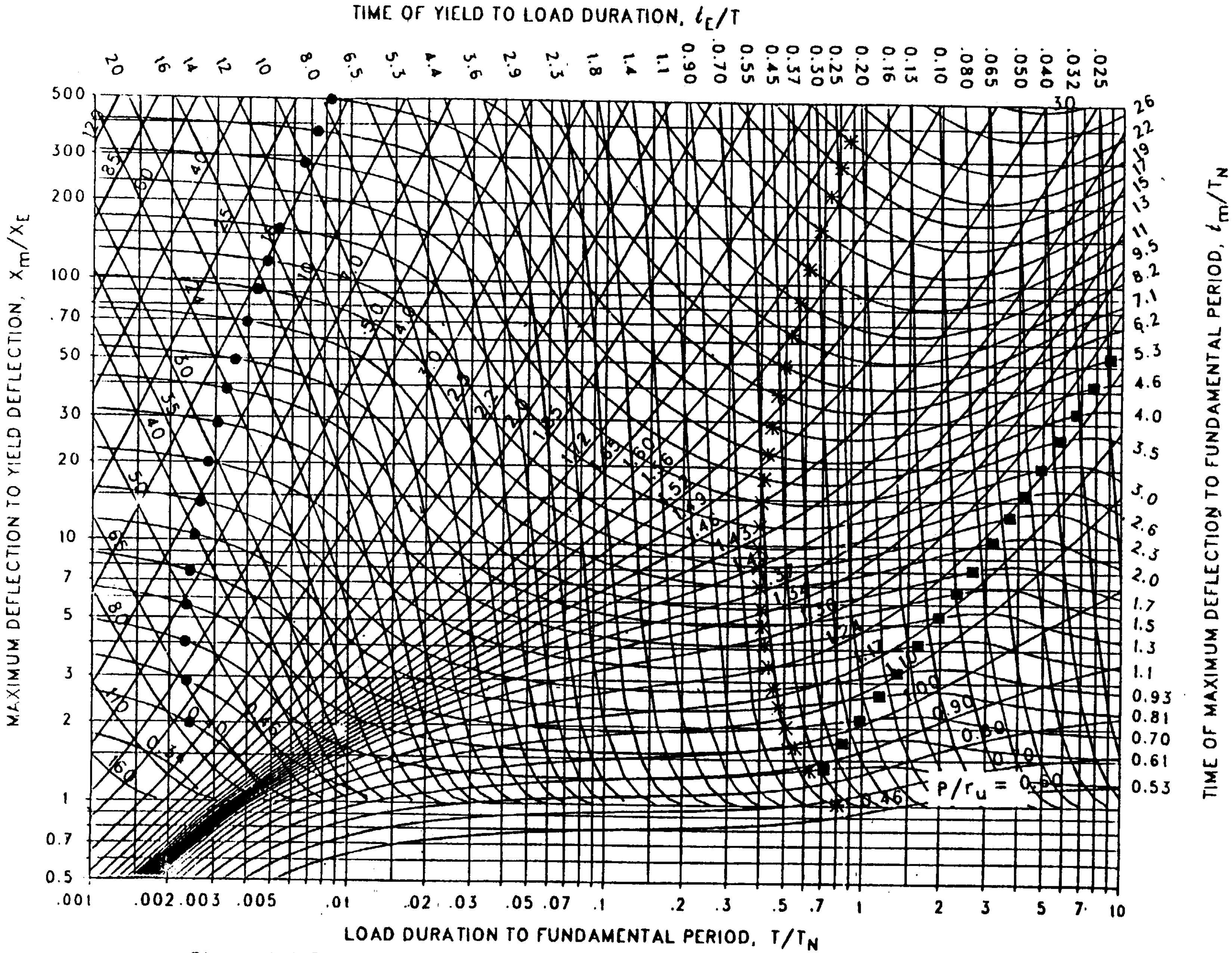


Figure 3-147 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.681, C_2 = 100.)

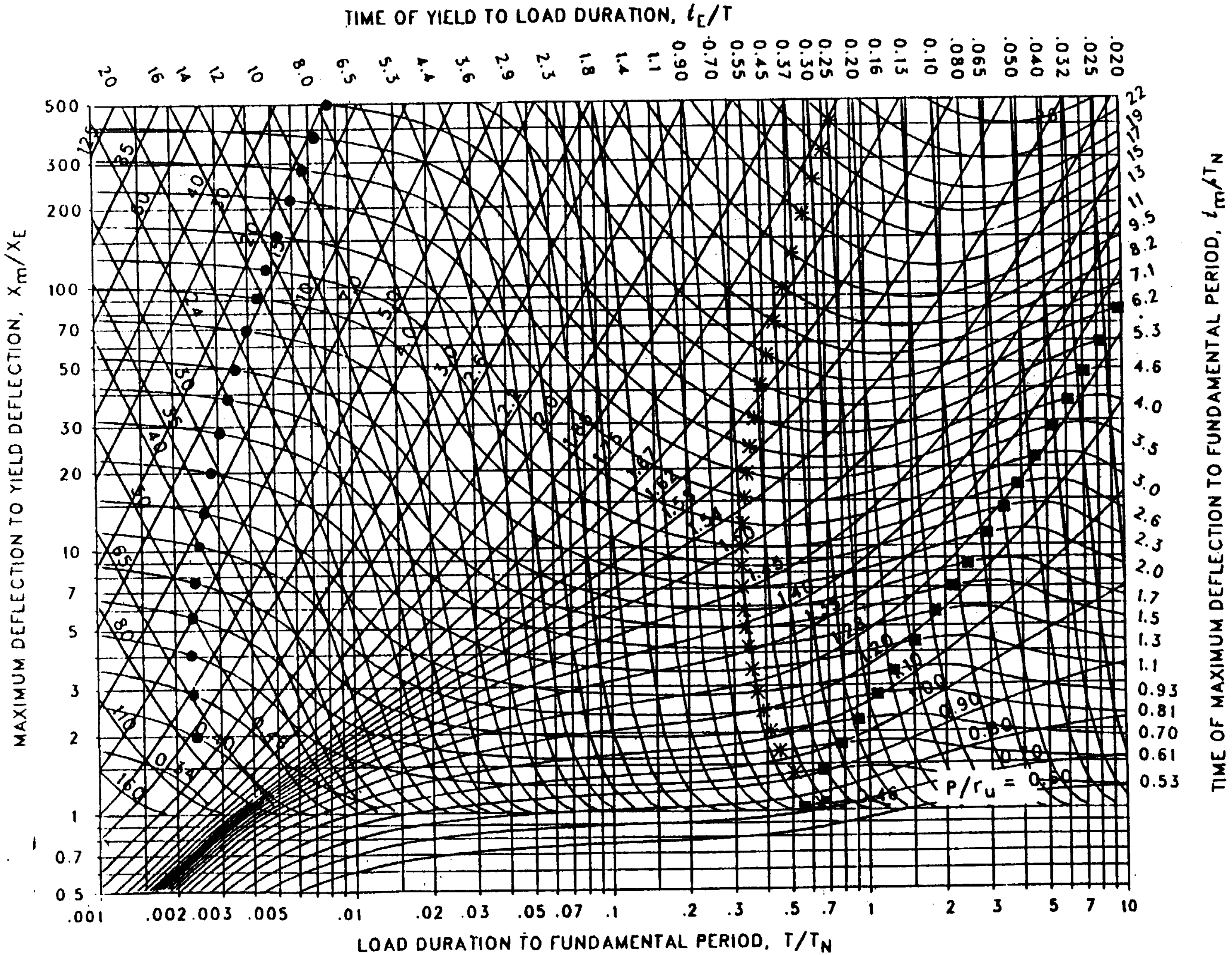


Figure 3-148 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.648, C_2 = 100.)

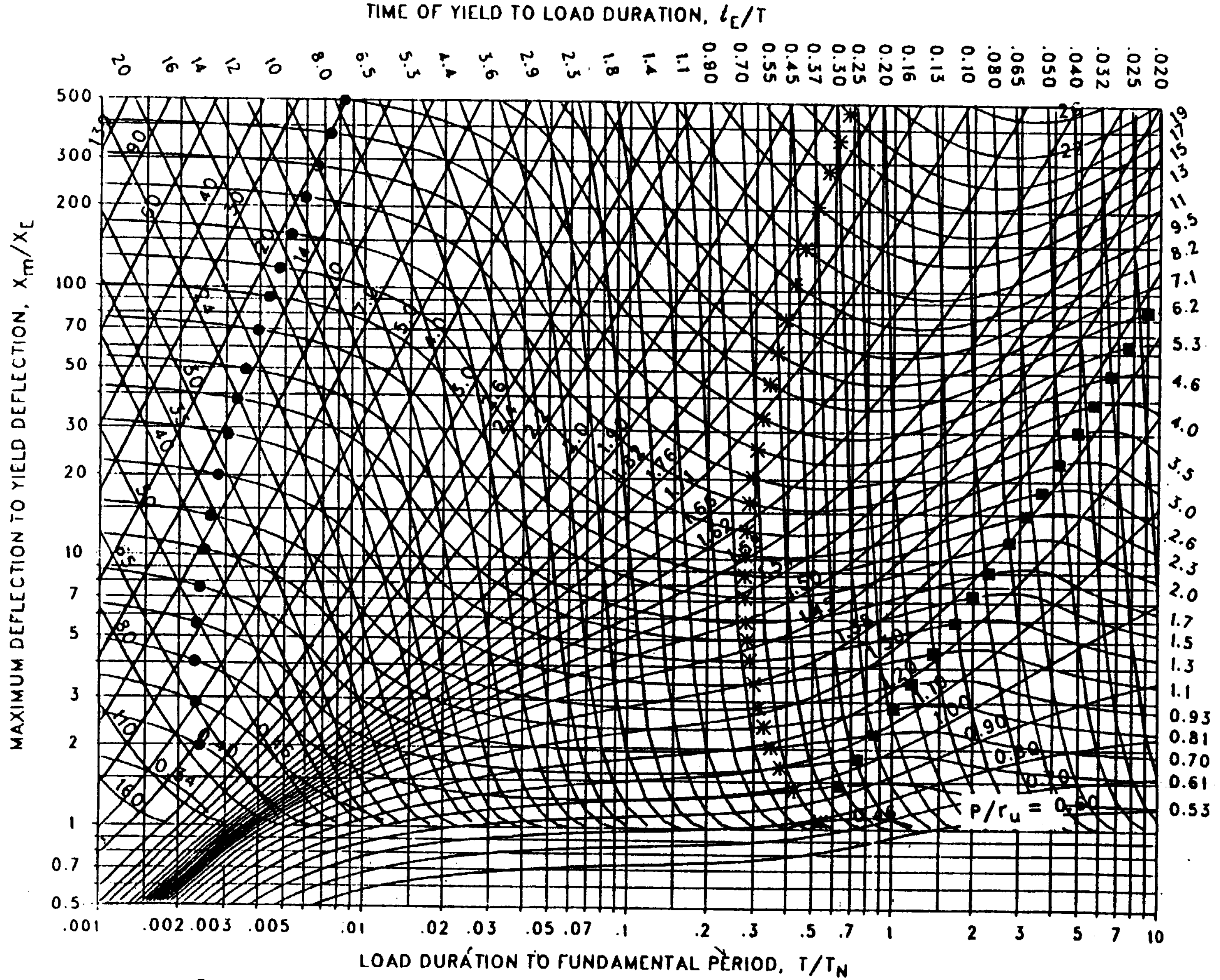


Figure 3-149 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.619, C_2 = 100.)

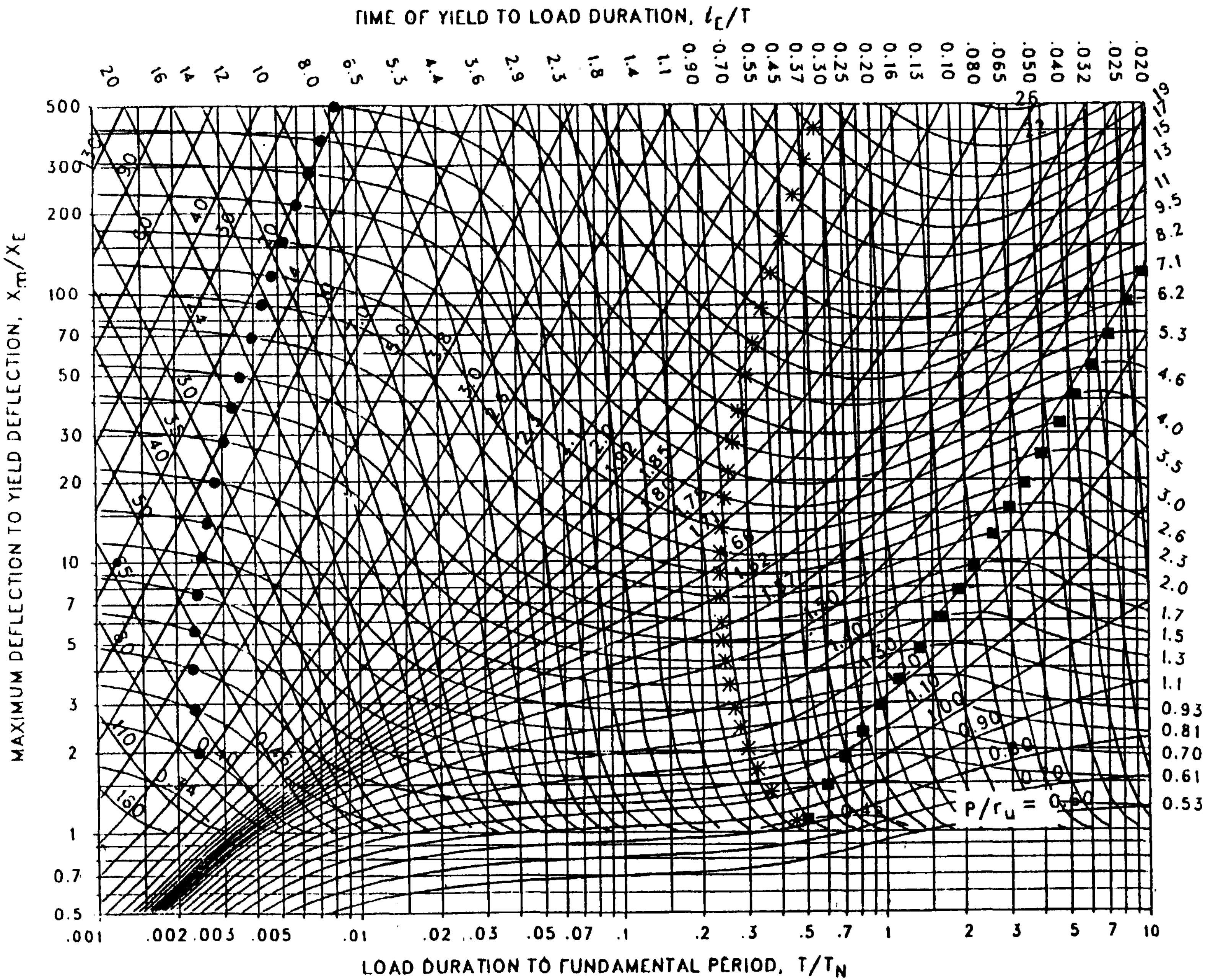


Figure 3-150 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.590, C_2 = 100.)

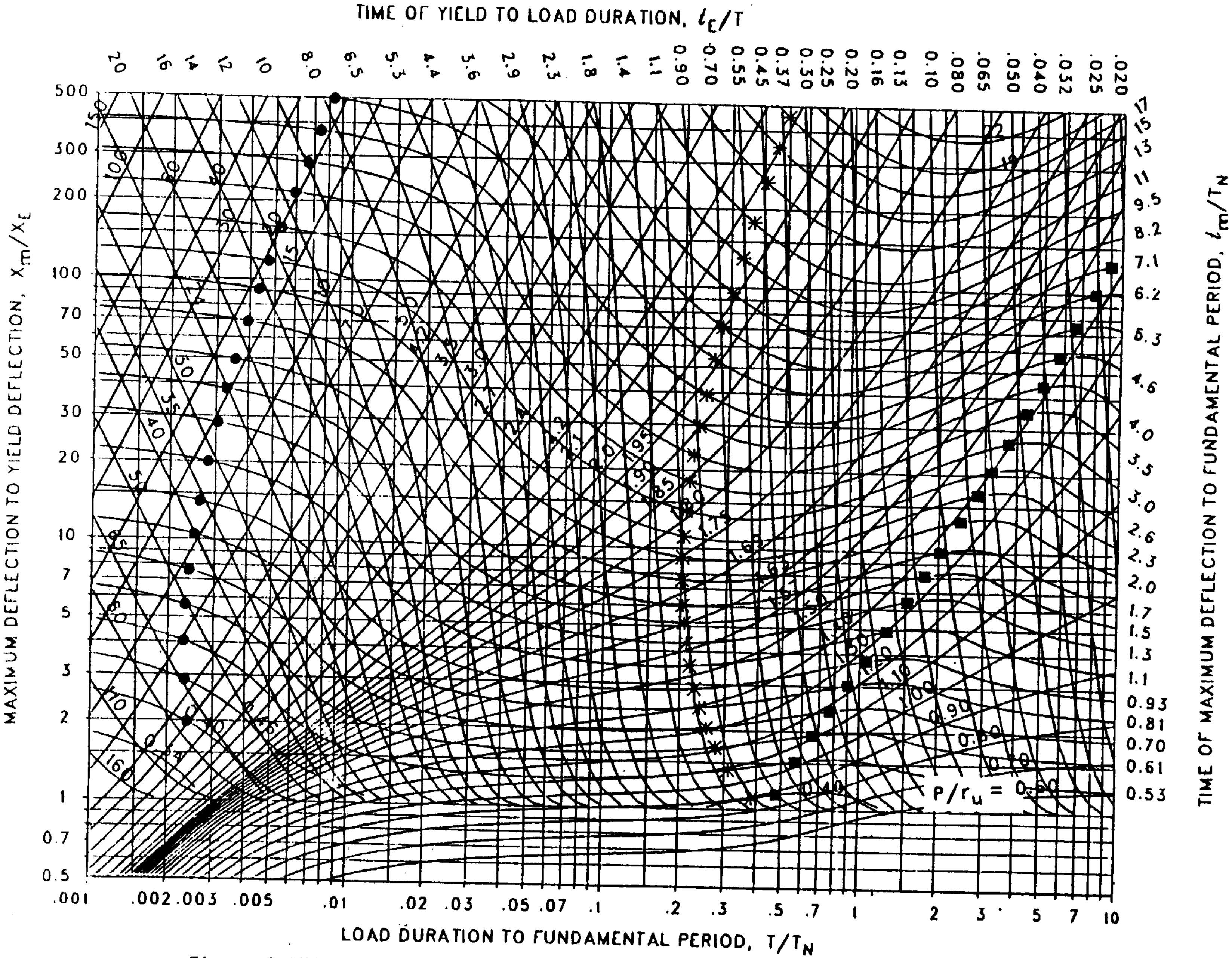


Figure 3-151 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.562, C_2 = 100.)

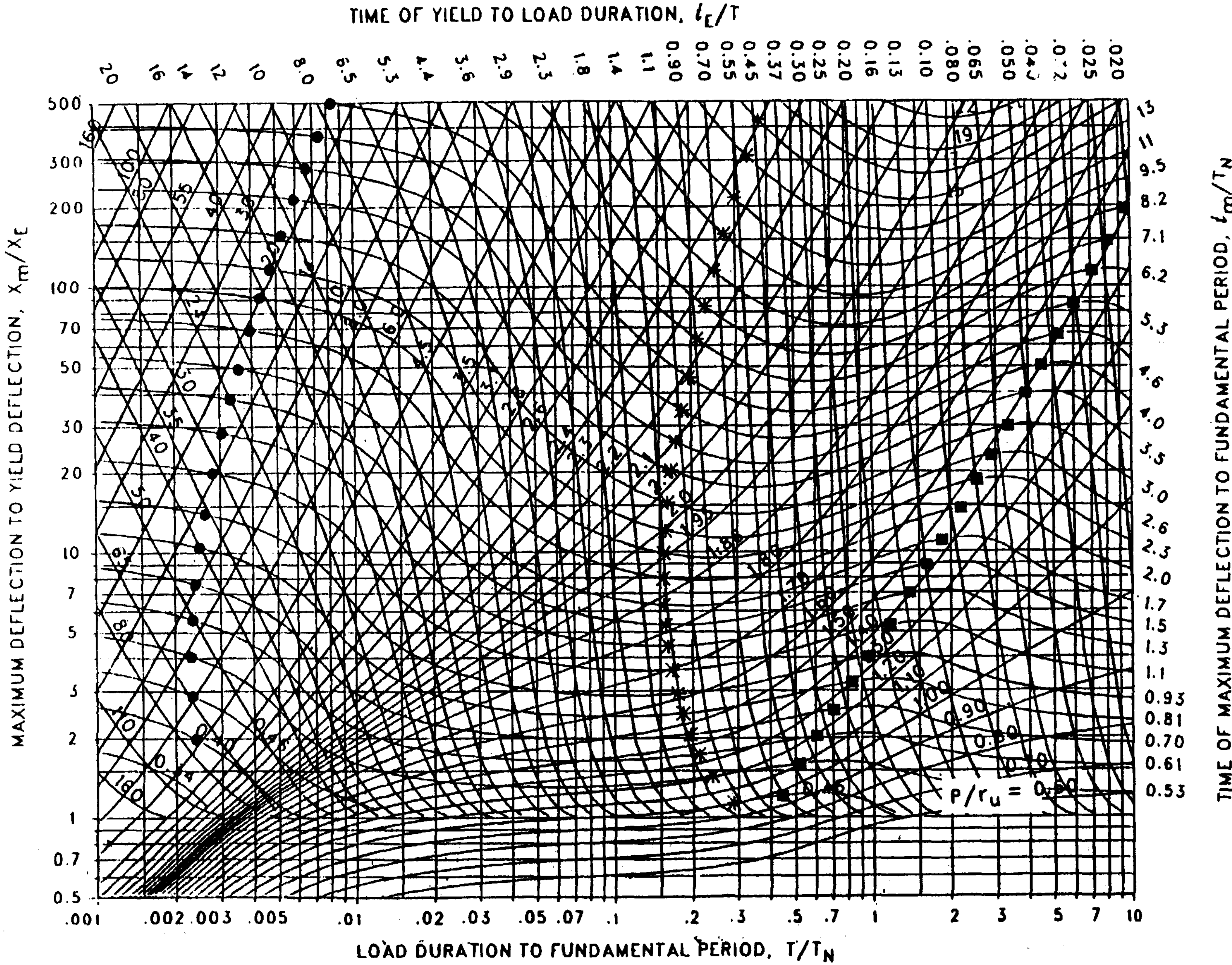


Figure 3-152 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.511, C_2 = 100.)

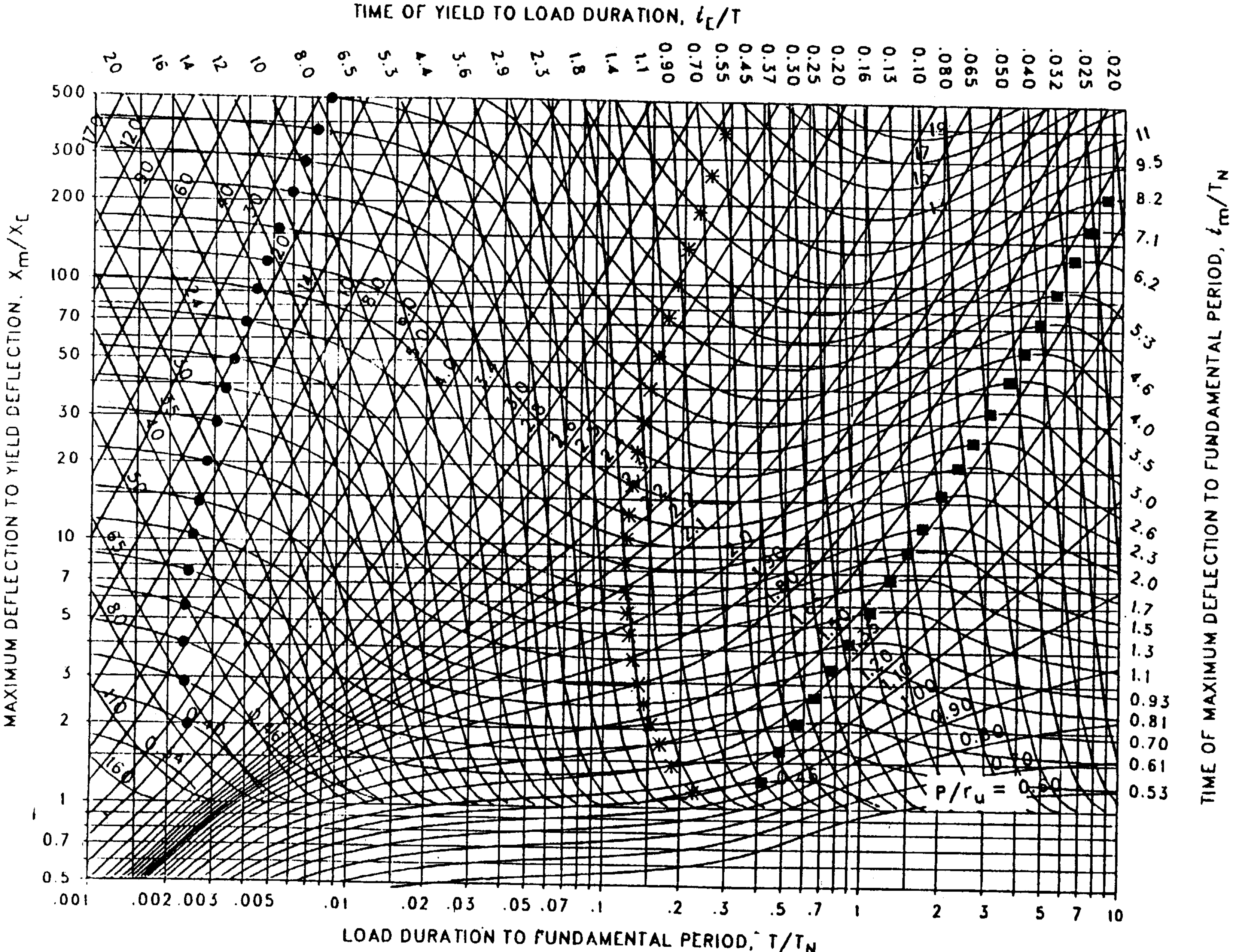


Figure 3-153 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.464, C_2 = 100.)

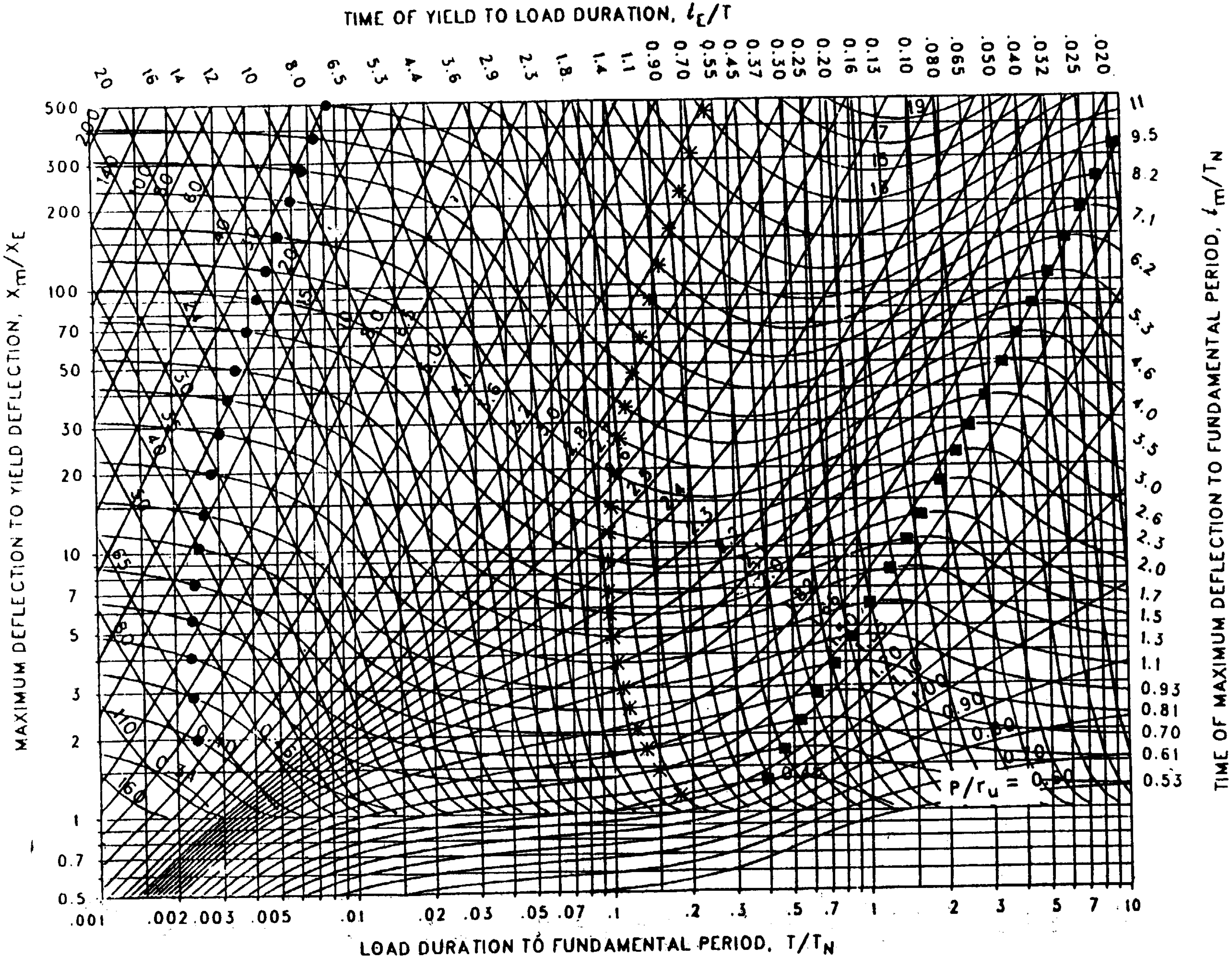


Figure 3-154 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.422, C_2 = 100.)

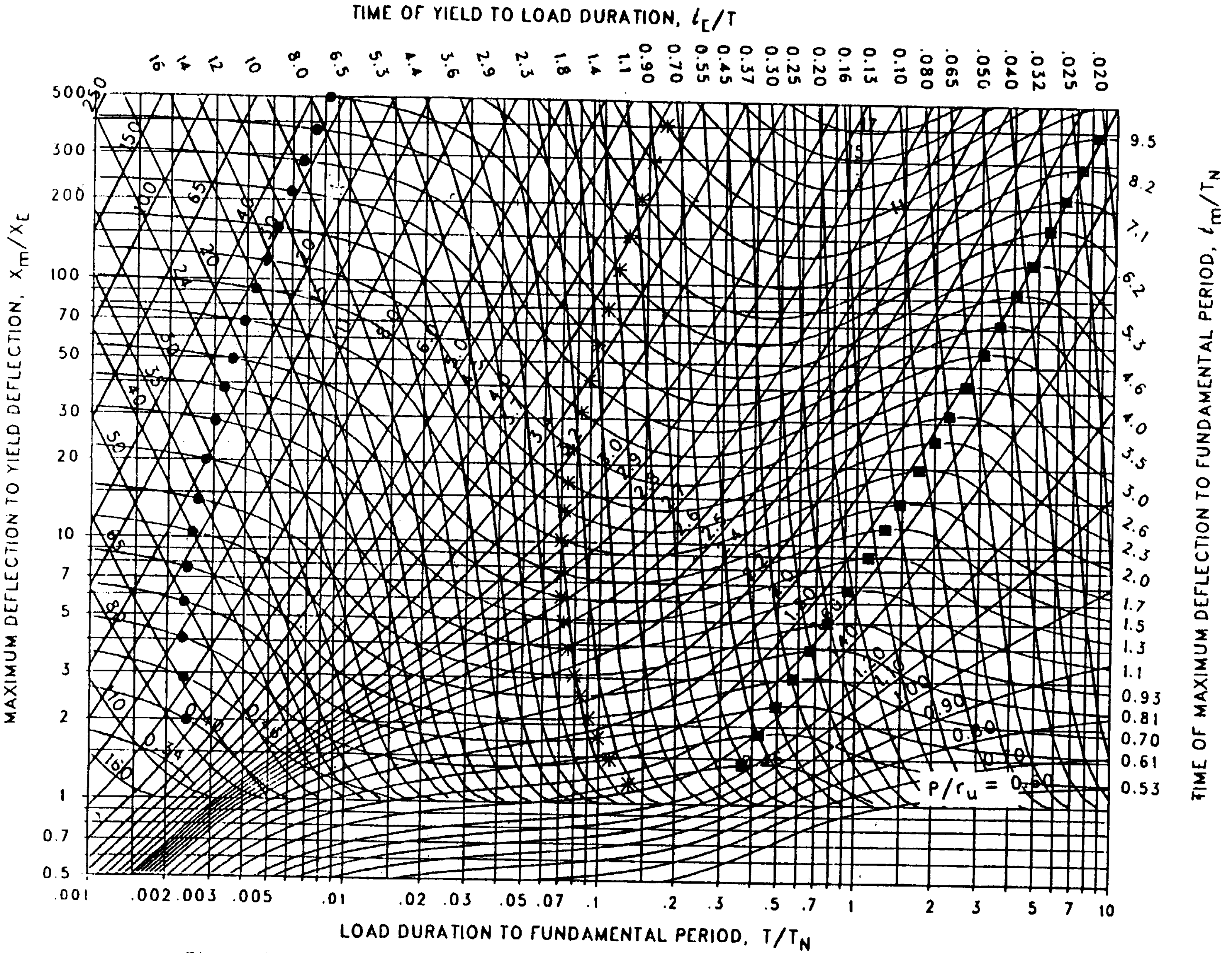


Figure 3-155 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.365, C_2 = 100.)

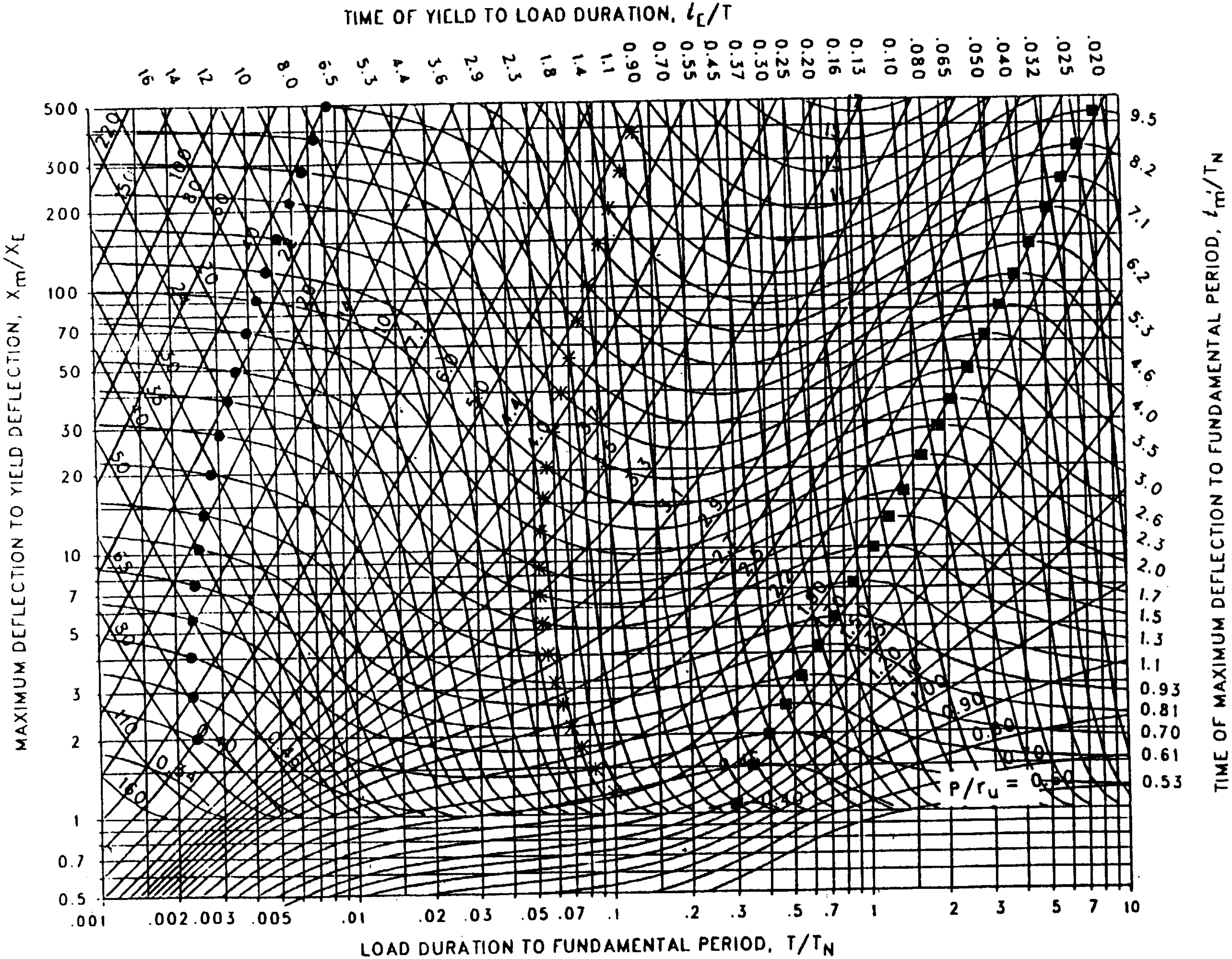


Figure 3-156 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.316, C_2 = 100.)

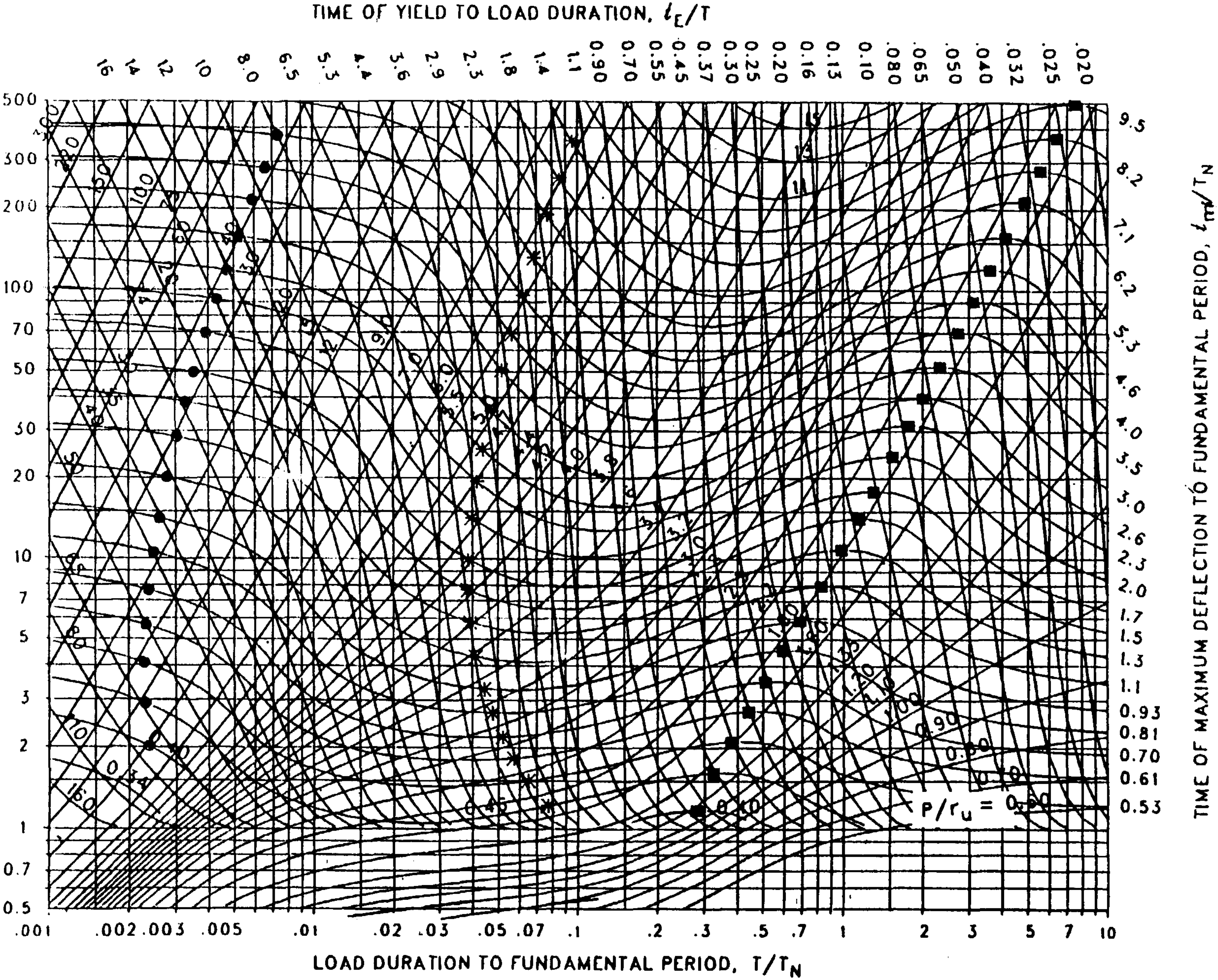


Figure 3-157 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.274, C_2 = 100.)

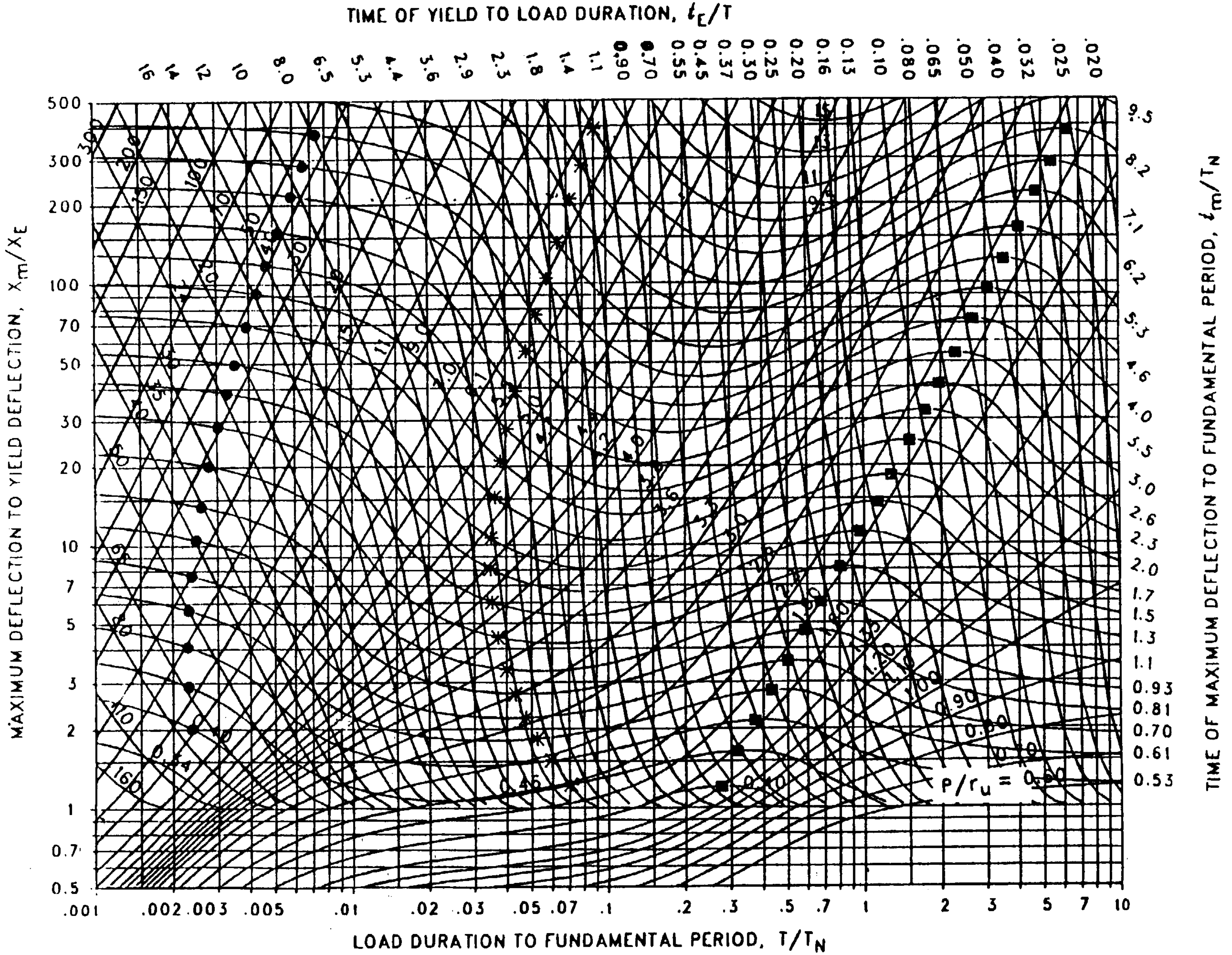


Figure 3-158 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.261, C_2 = 100.)

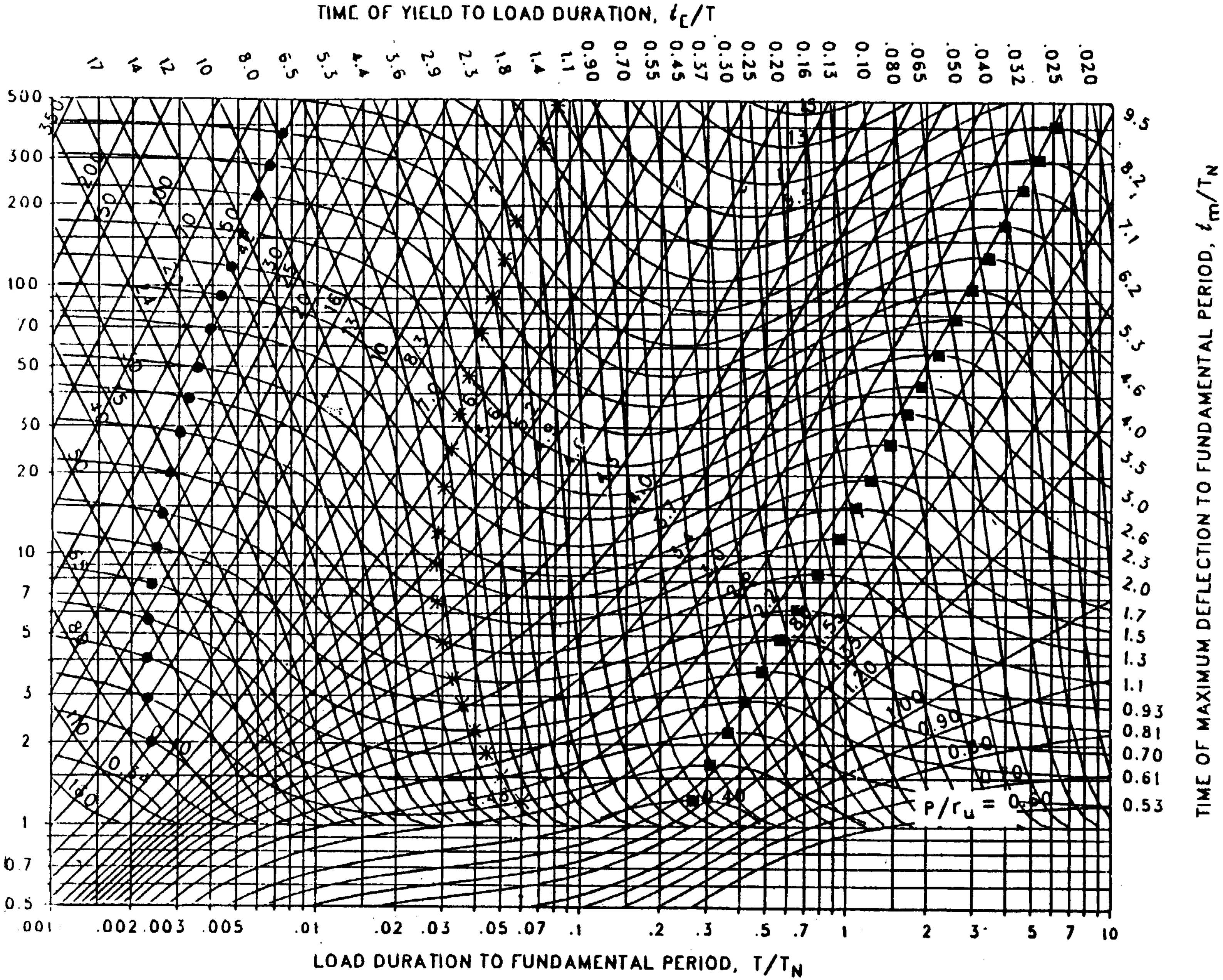


Figure 3-159 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.237, C_2 = 100.)

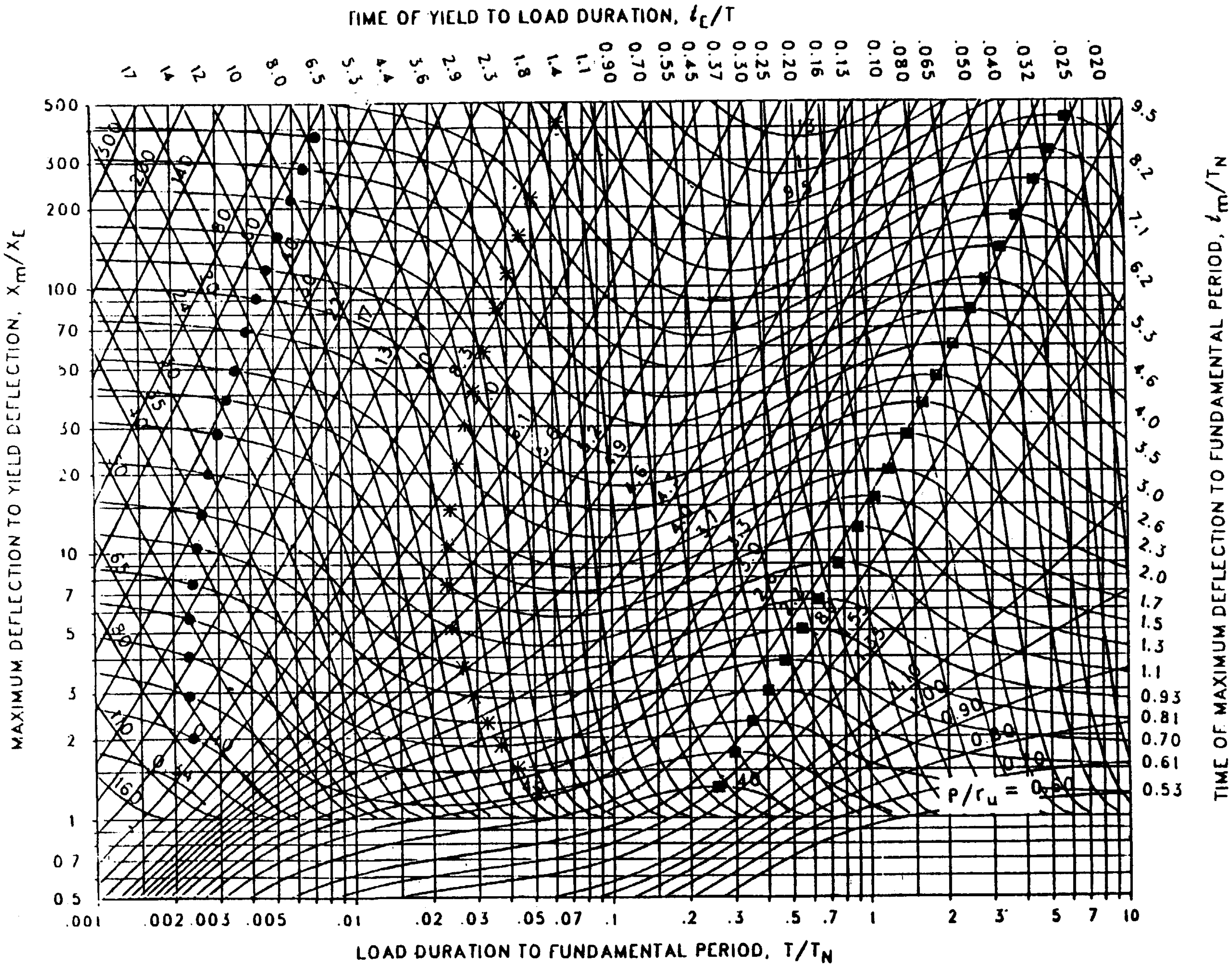


Figure 3-160 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.215, C_2 = 100.)

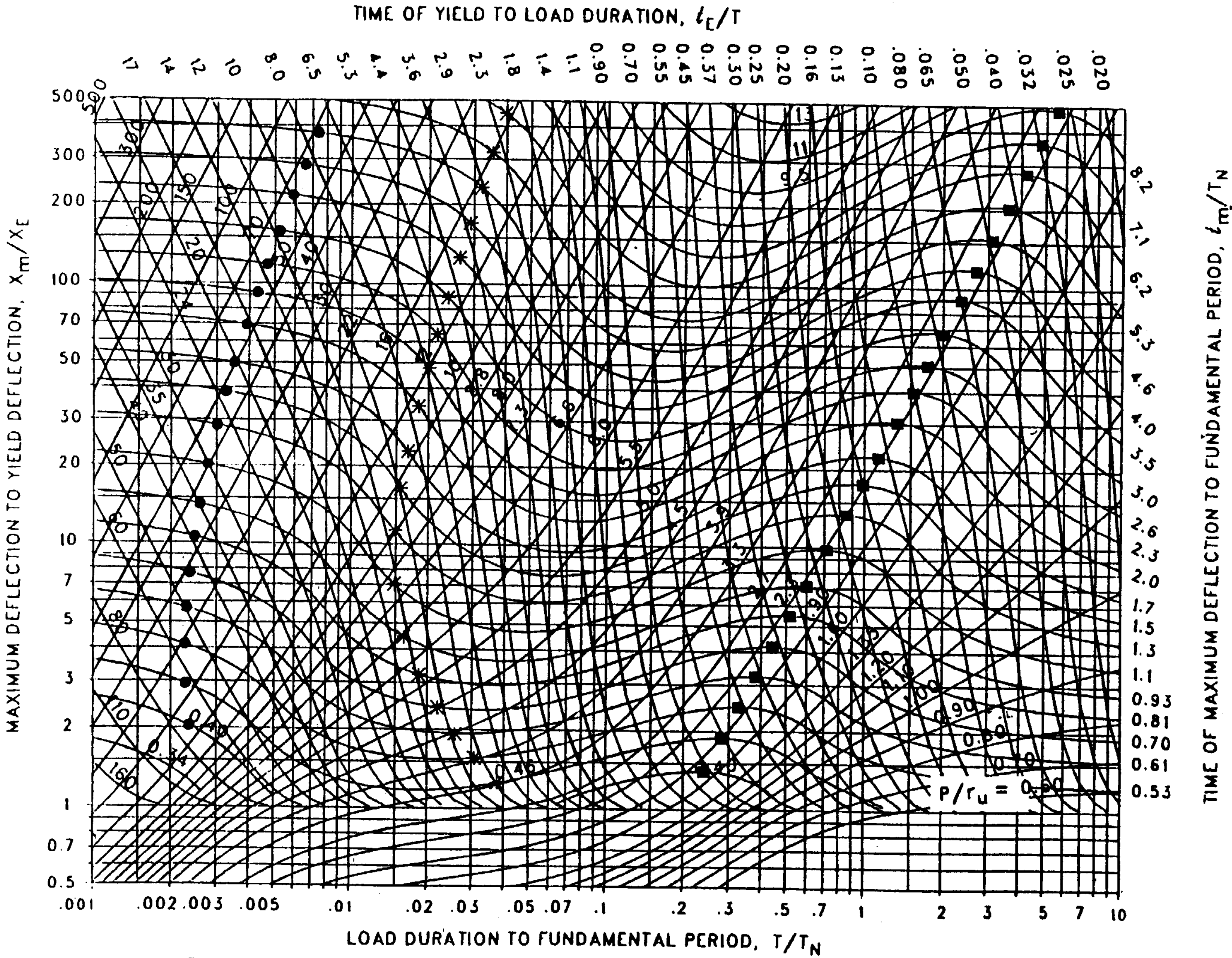


Figure 3-161 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.178, C_2 = 100.)

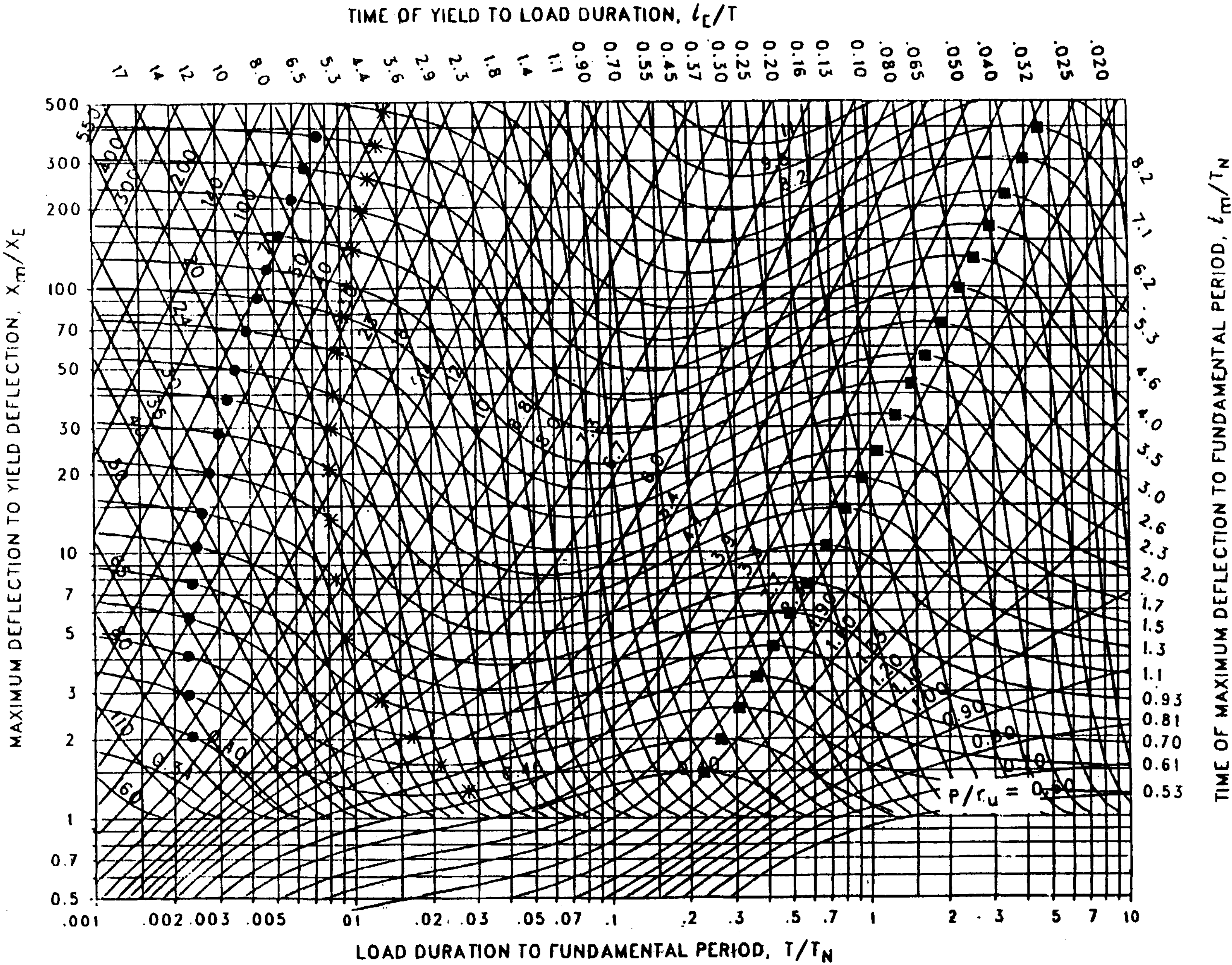


Figure 3-162 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.147, C_2 = 100.)

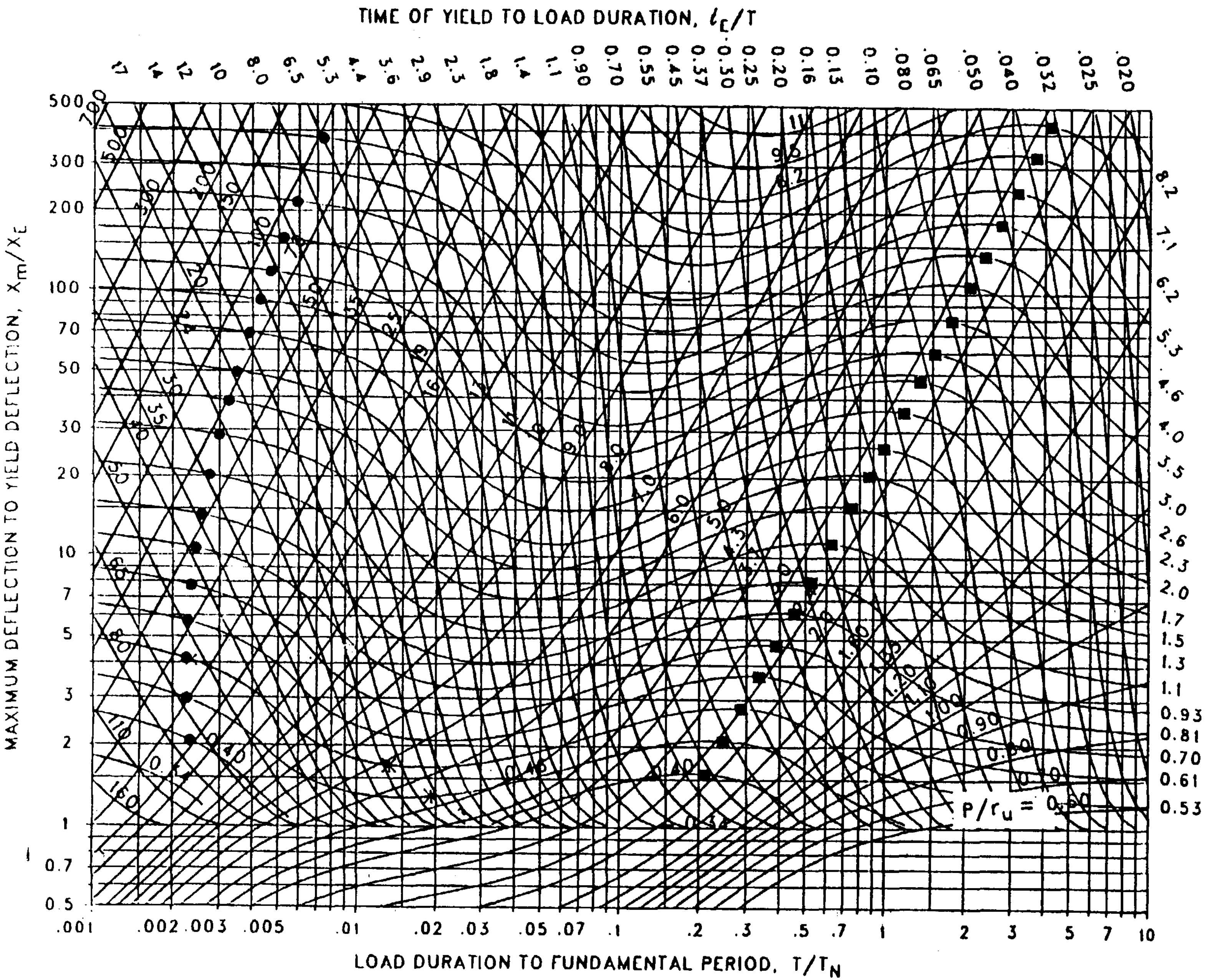


Figure 3-163 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.121, C_2 = 100.)

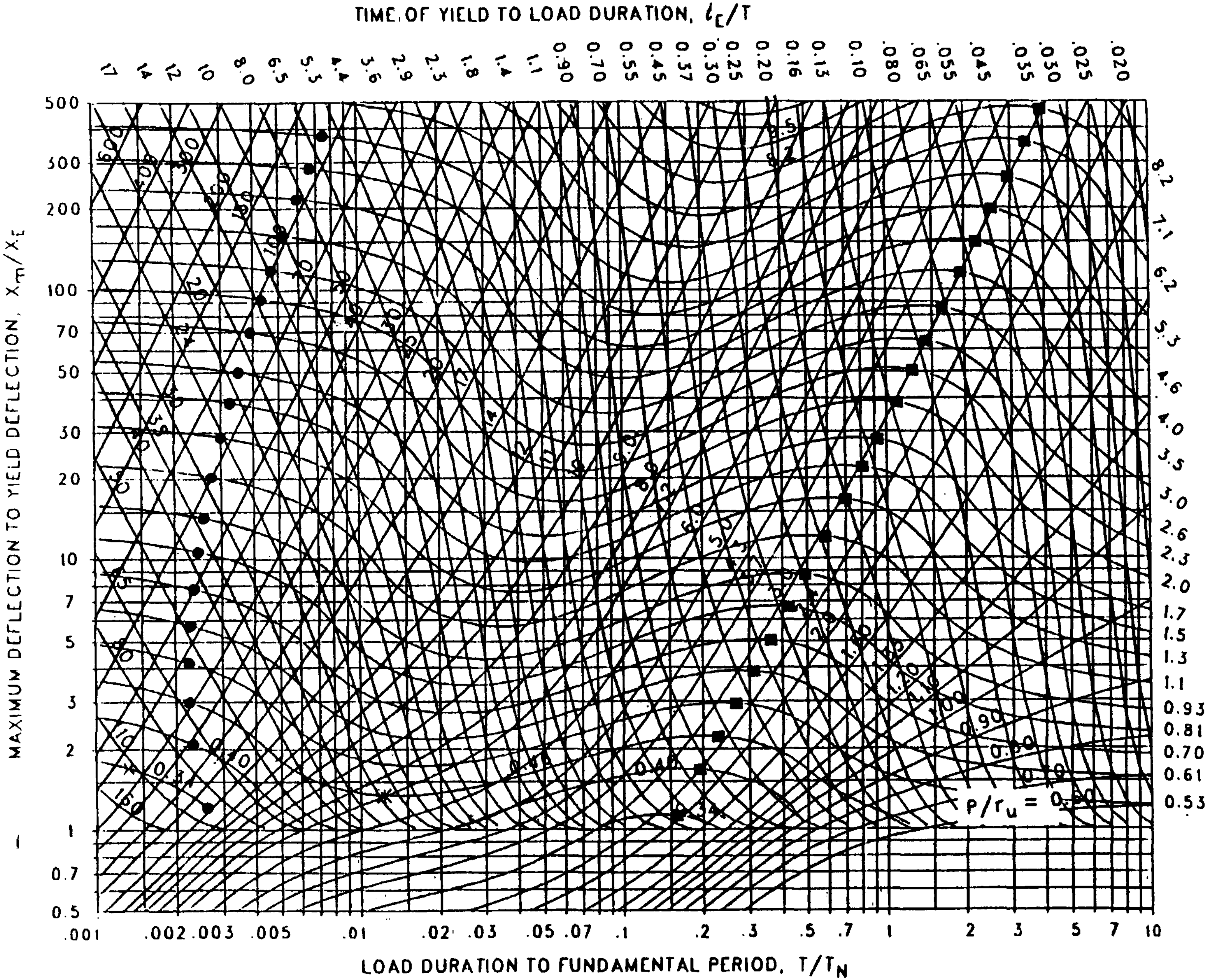


Figure 3-164 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.100, C_2 = 100.)

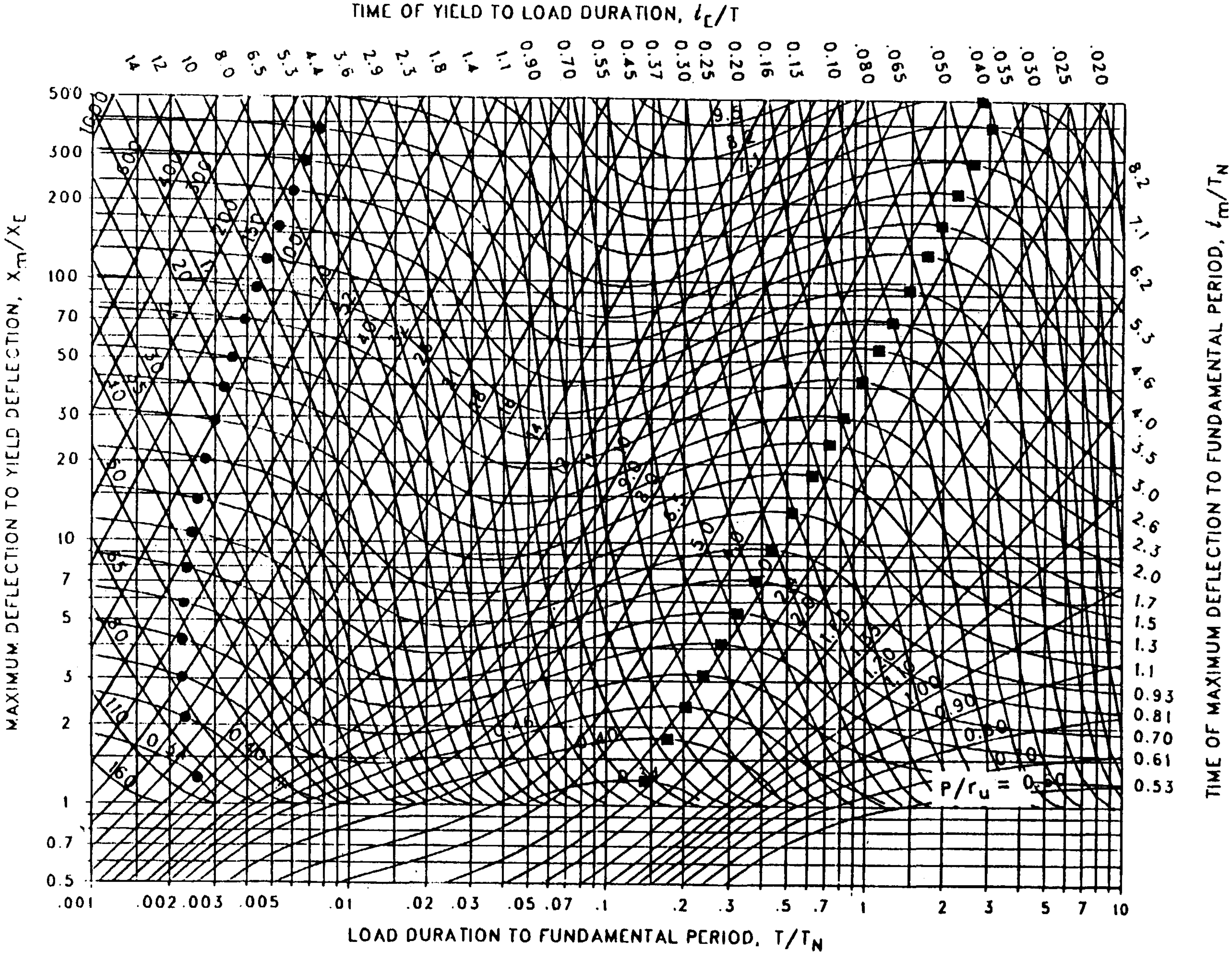


Figure 3-165   Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.075, C_2 = 100.)

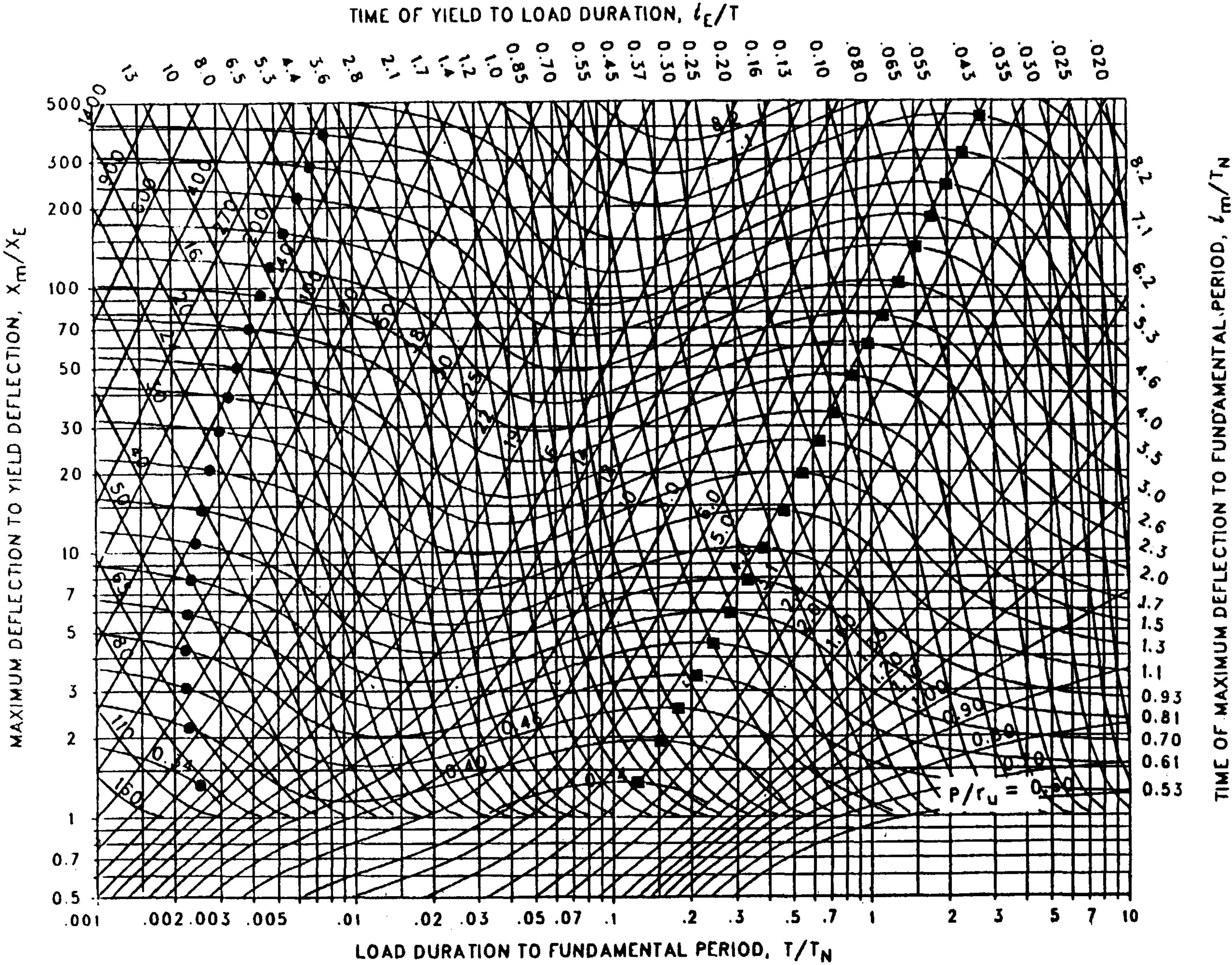


Figure 3-166 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.056, C_2 = 100.)

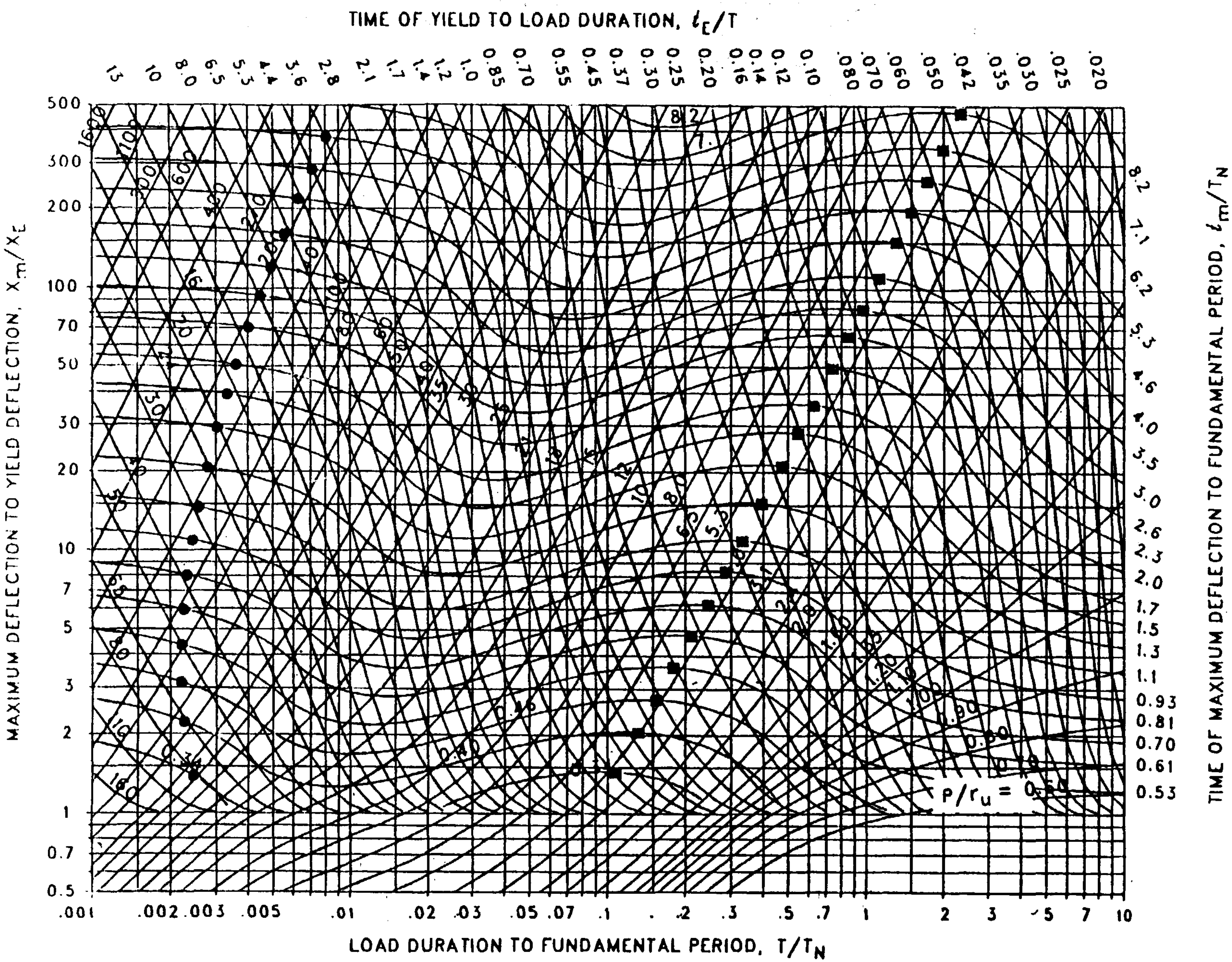


Figure 3-167 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.042, C_2 = 100.)

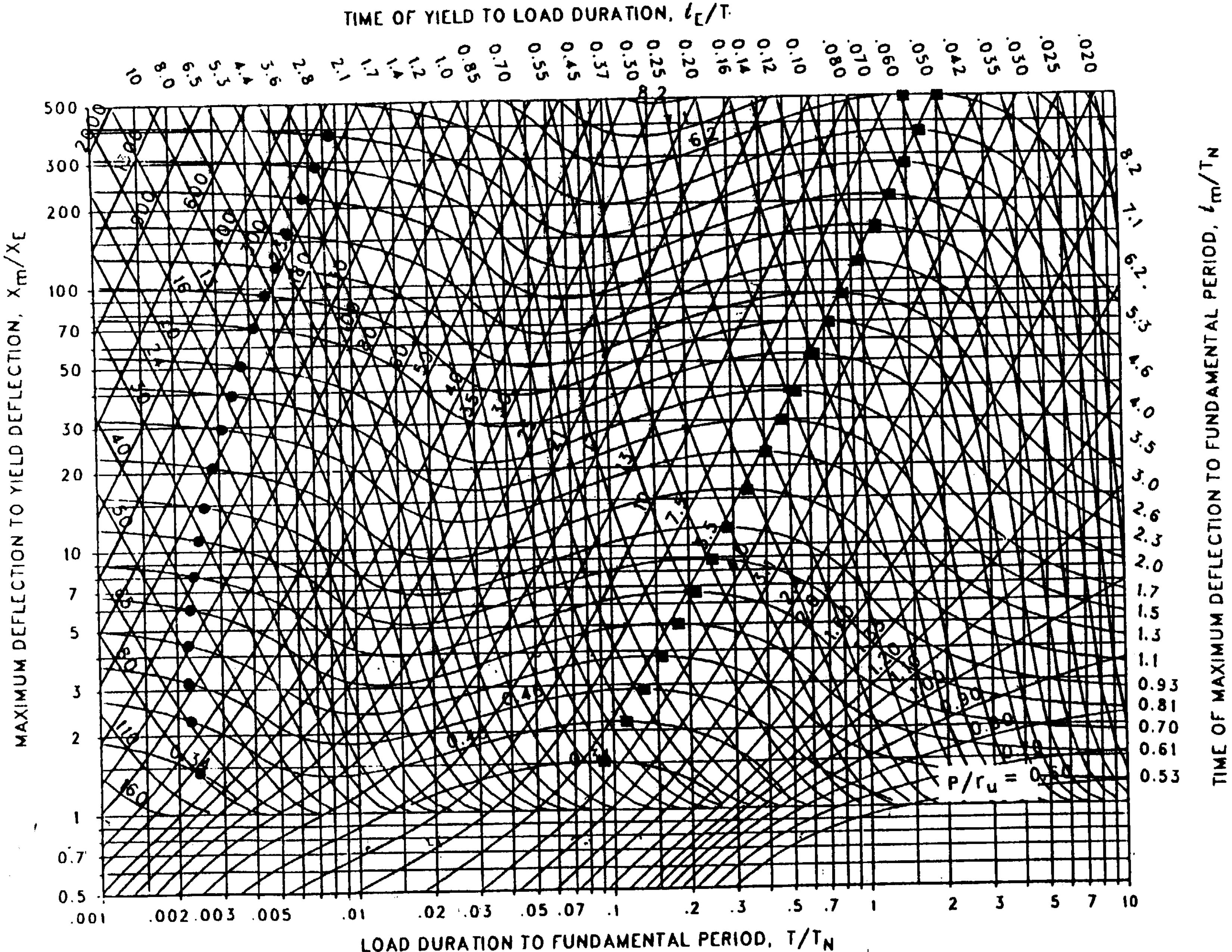


Figure 3-168 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.032, C_2 = 100.)

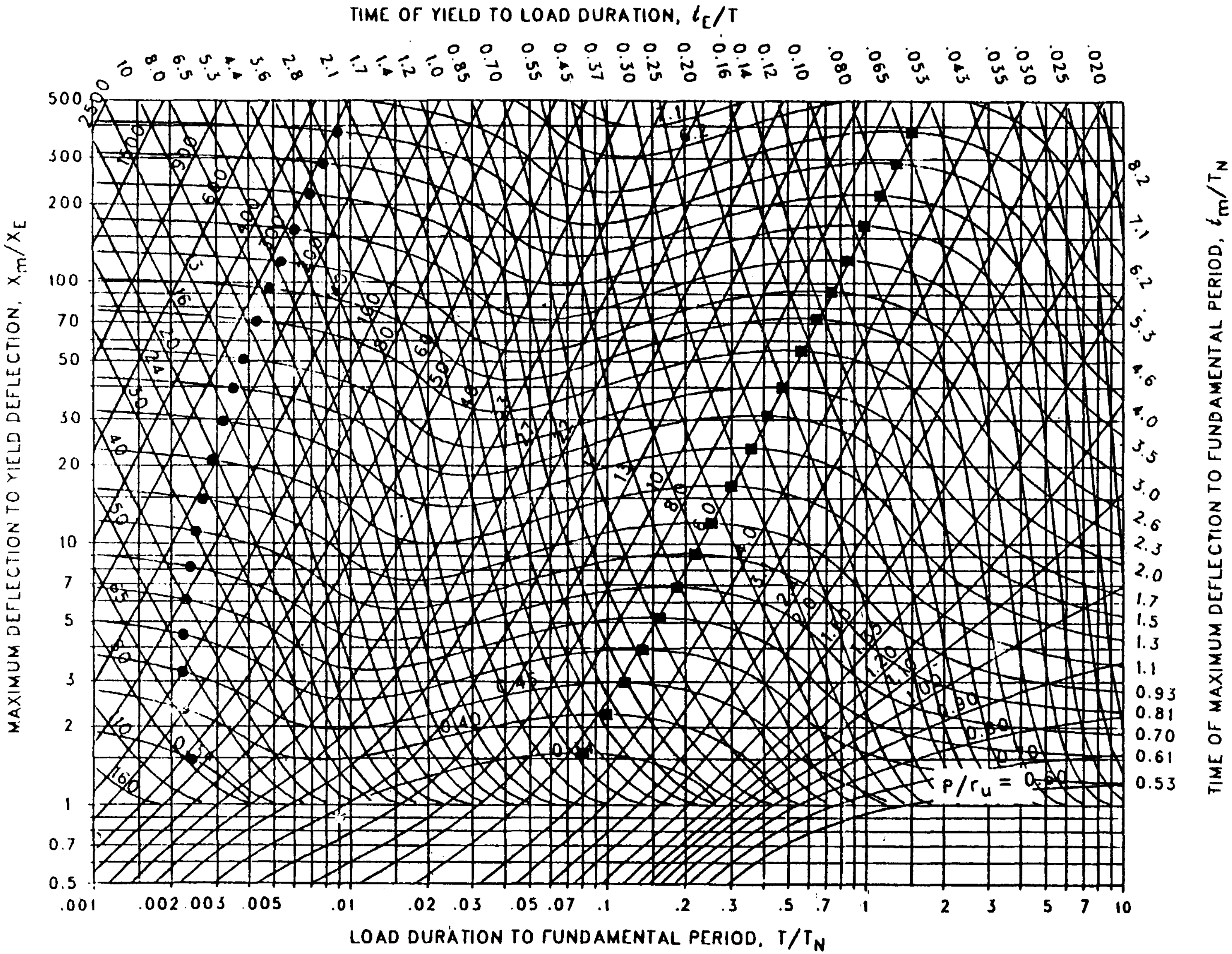


Figure 3-169 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.026, C_2 = 100.)

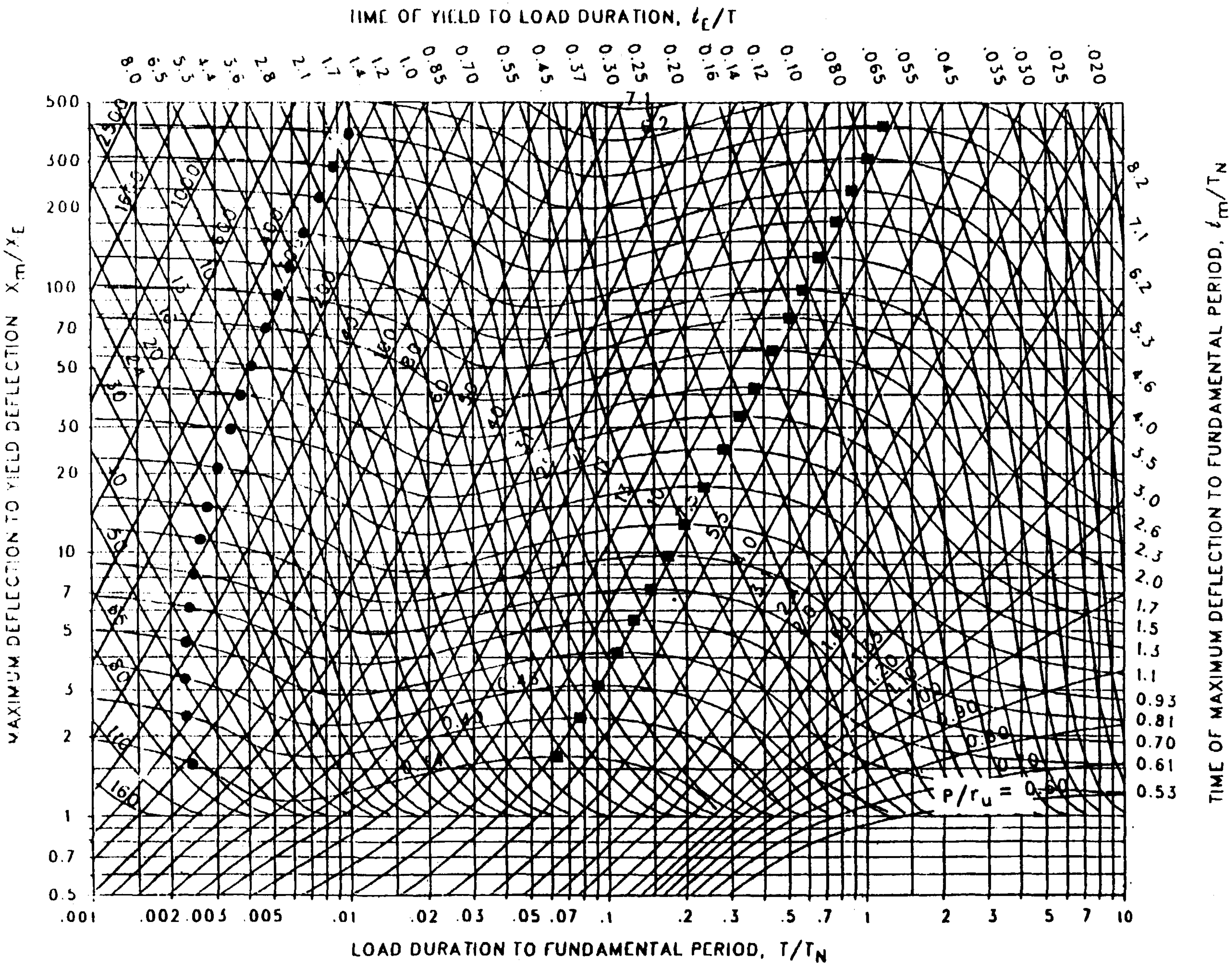


Figure 3-170 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.018, C_2 = 100.)

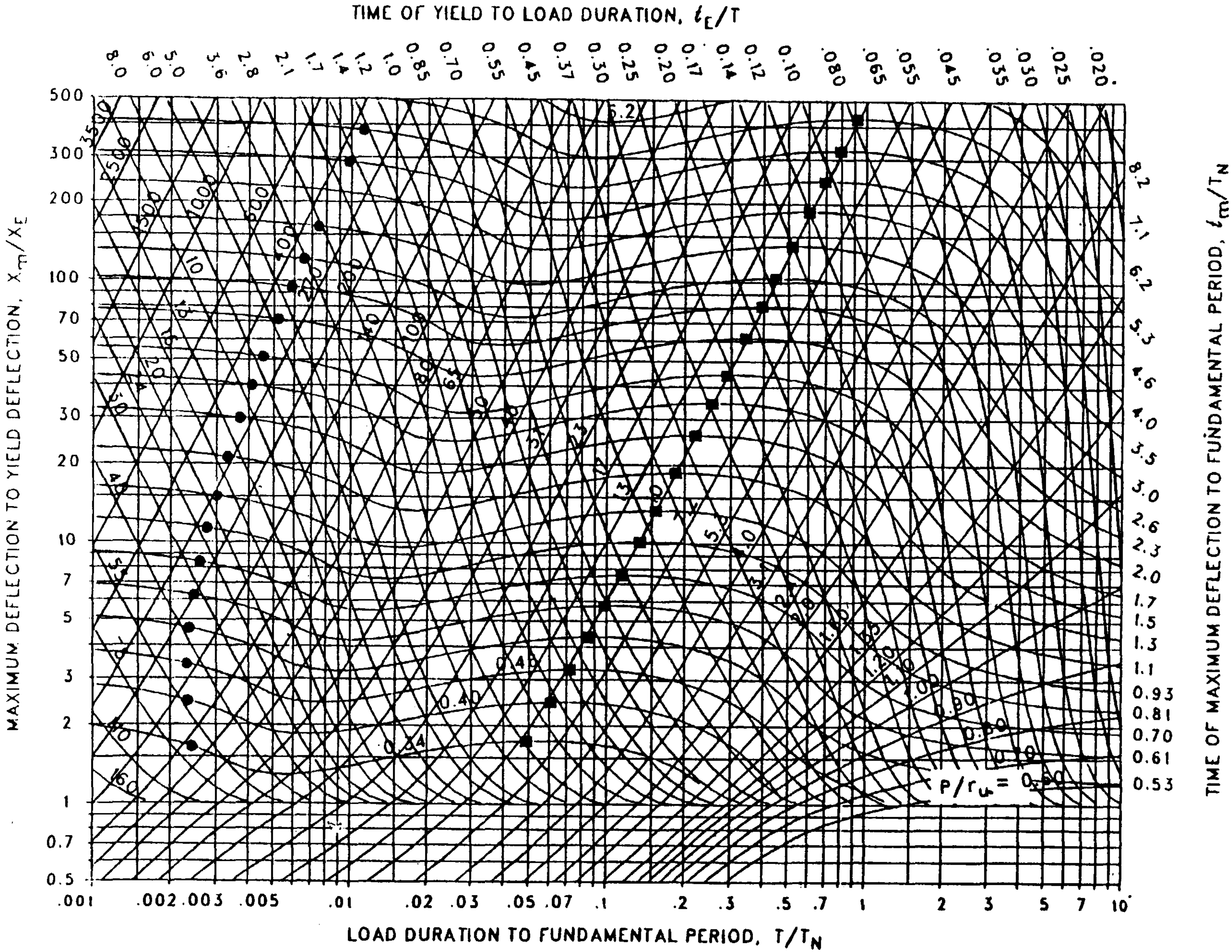


Figure 3-171 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.013, C_2 = 100.)

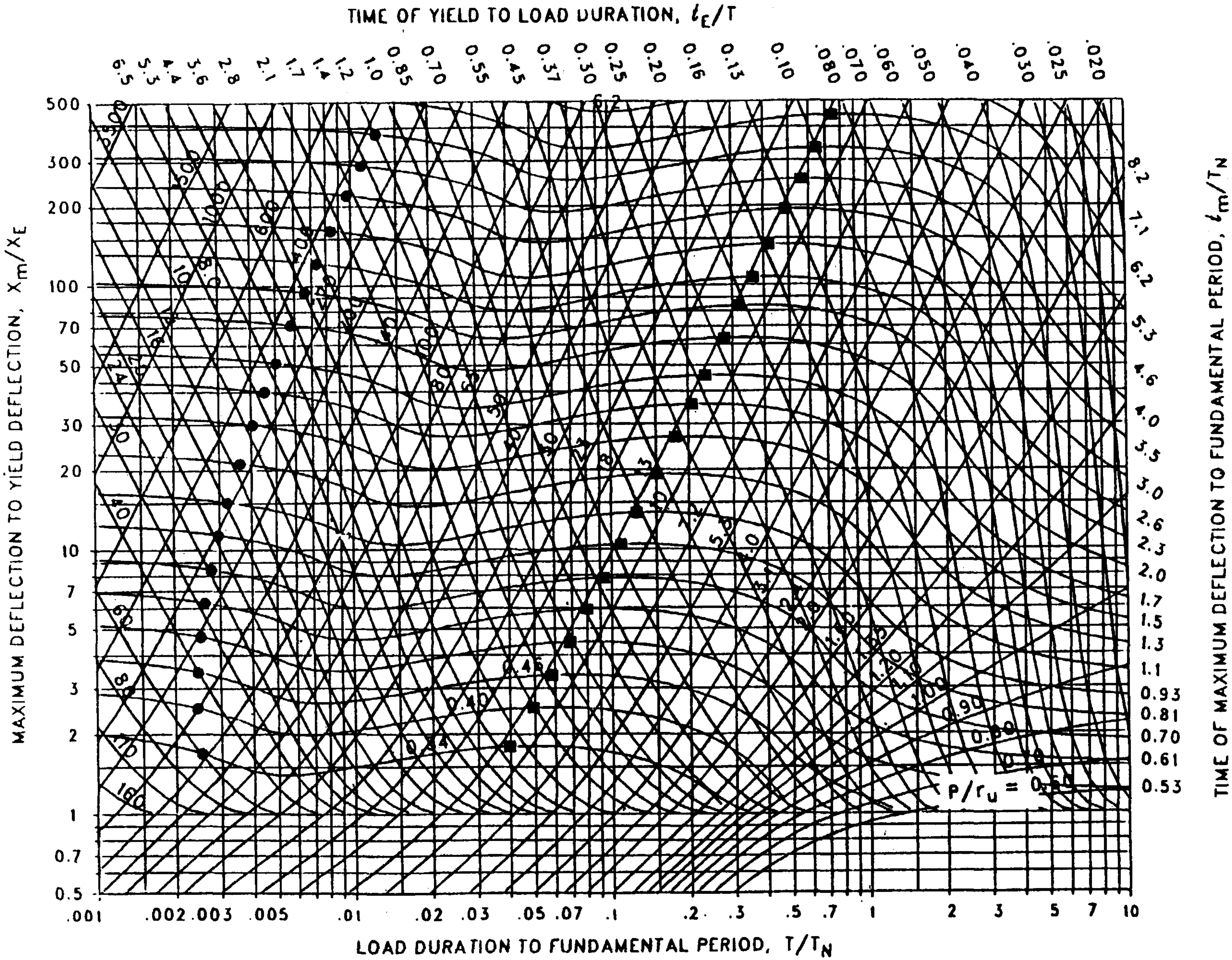


Figure 3-172 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.010, C_2 = 100.)

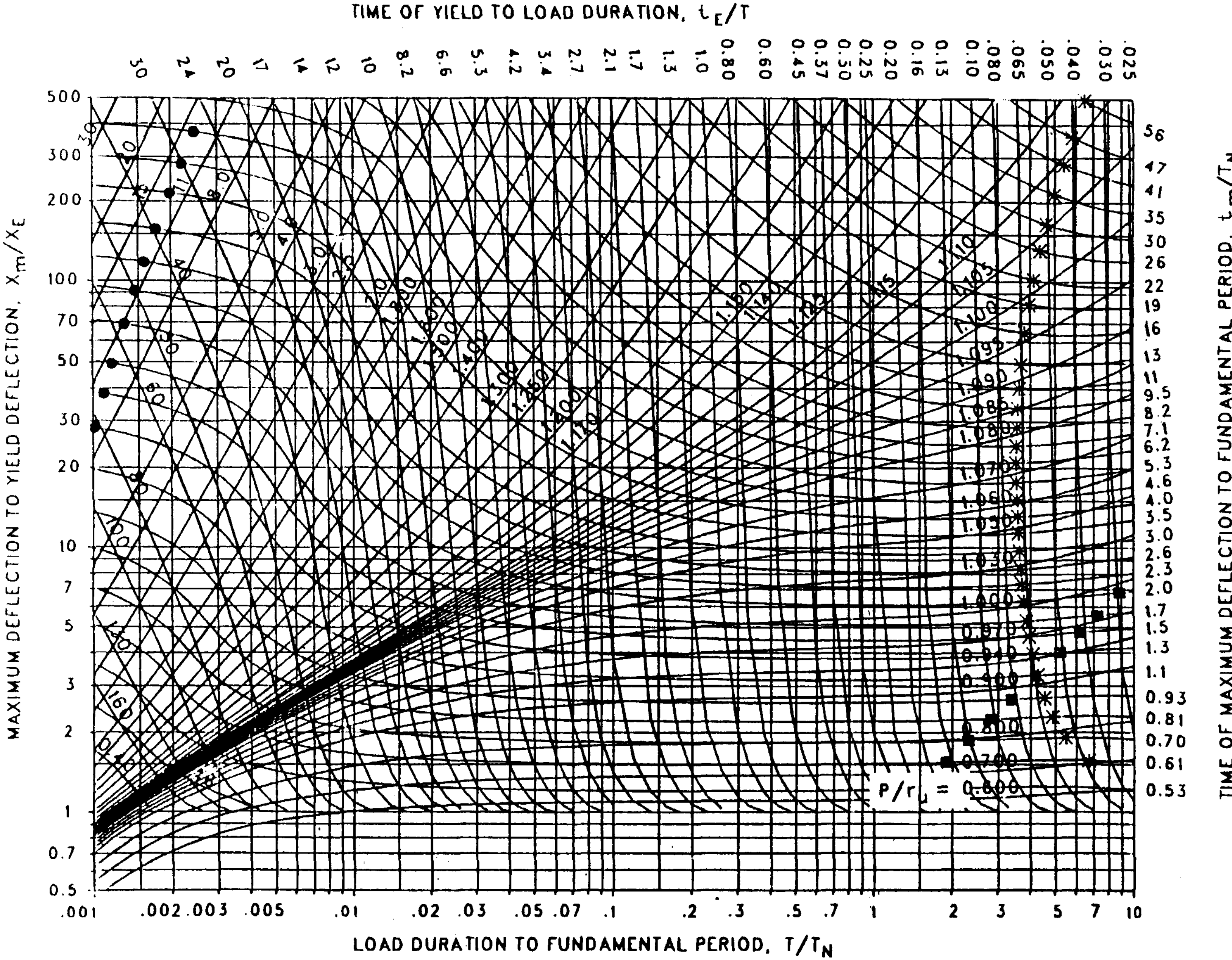


Figure 3-173 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.909, C_2 = 300.)

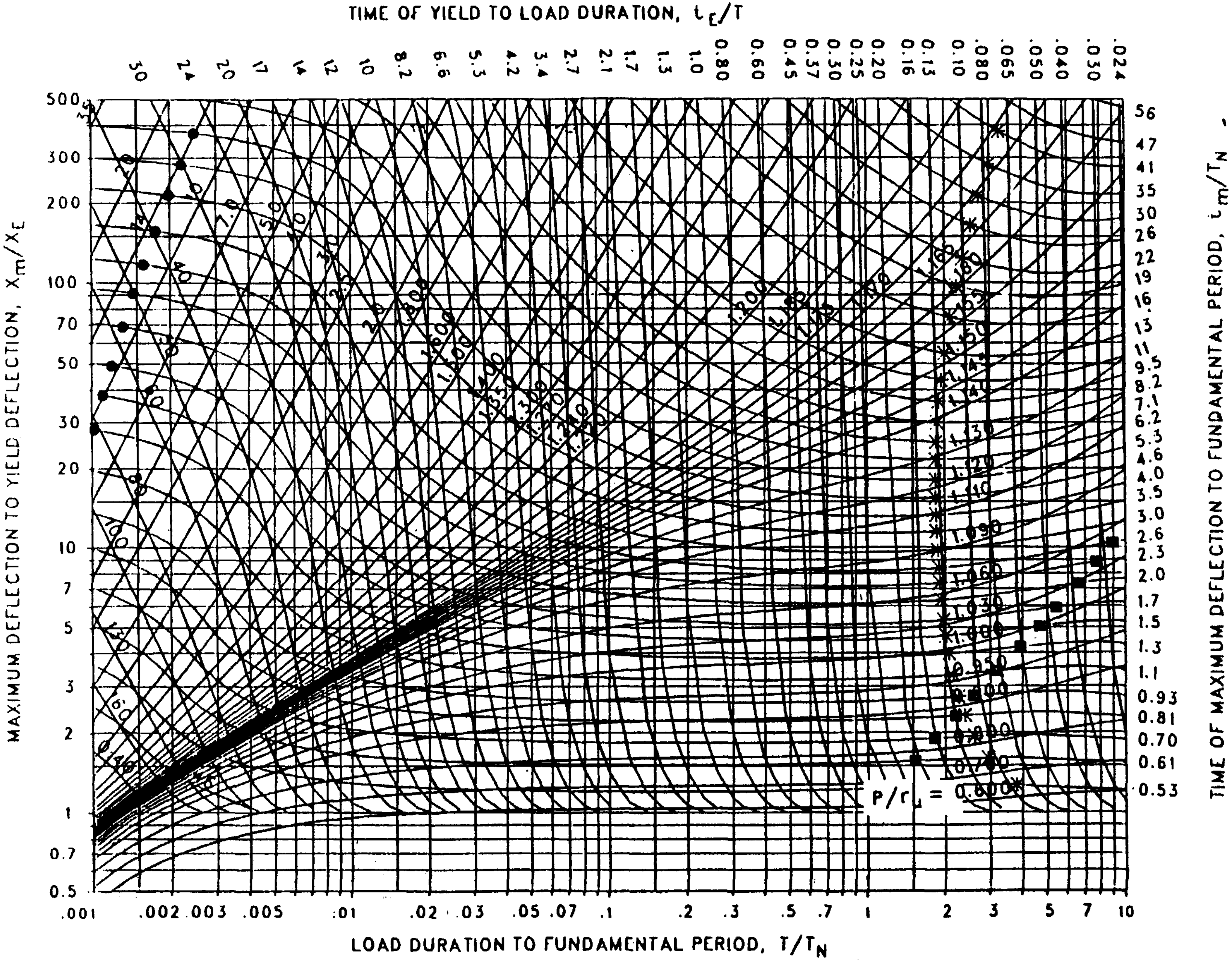


Figure 3-174 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.866, C_2 = 300.)

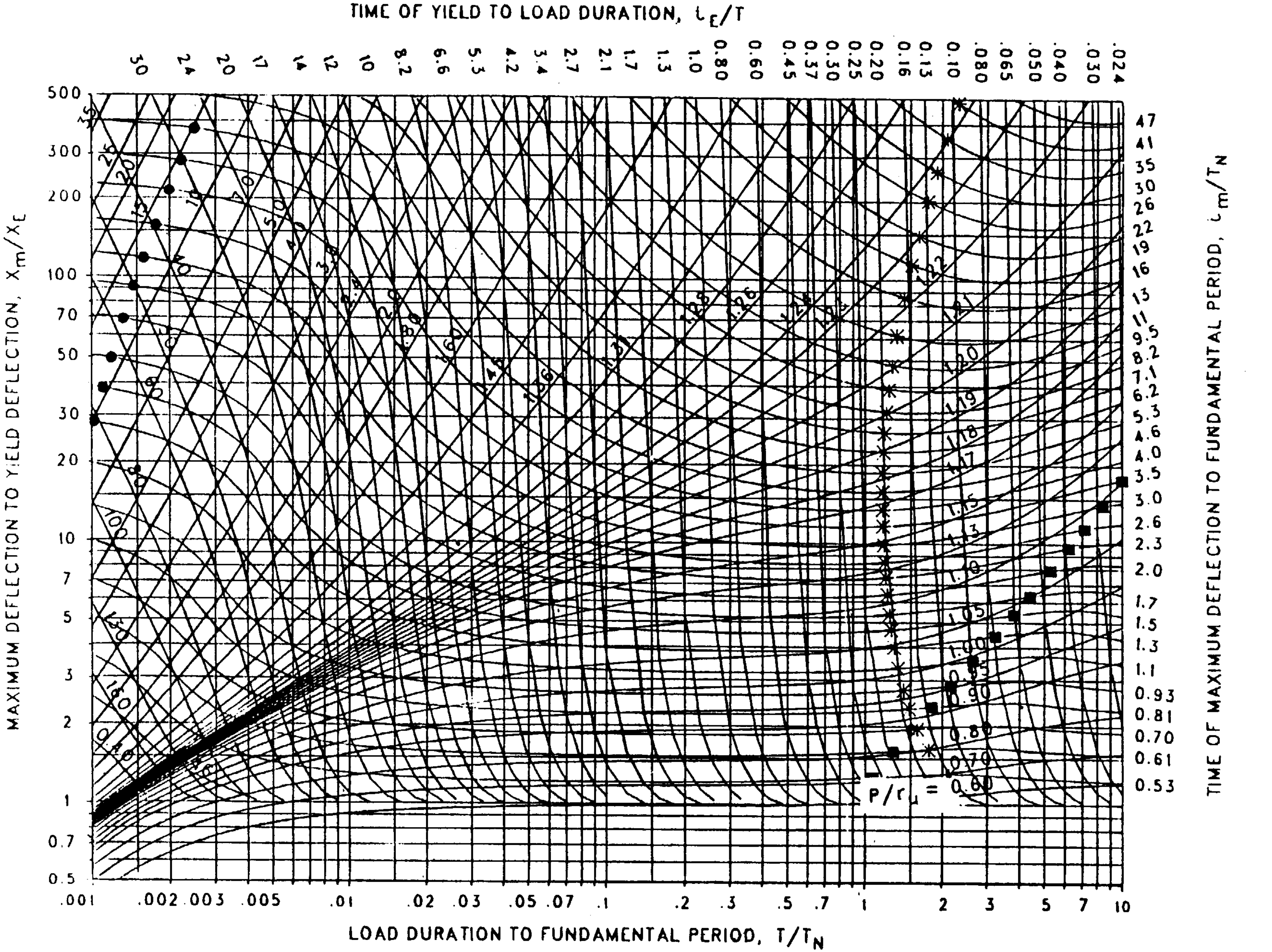


Figure 3-175 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.825, C_2 = 300.)

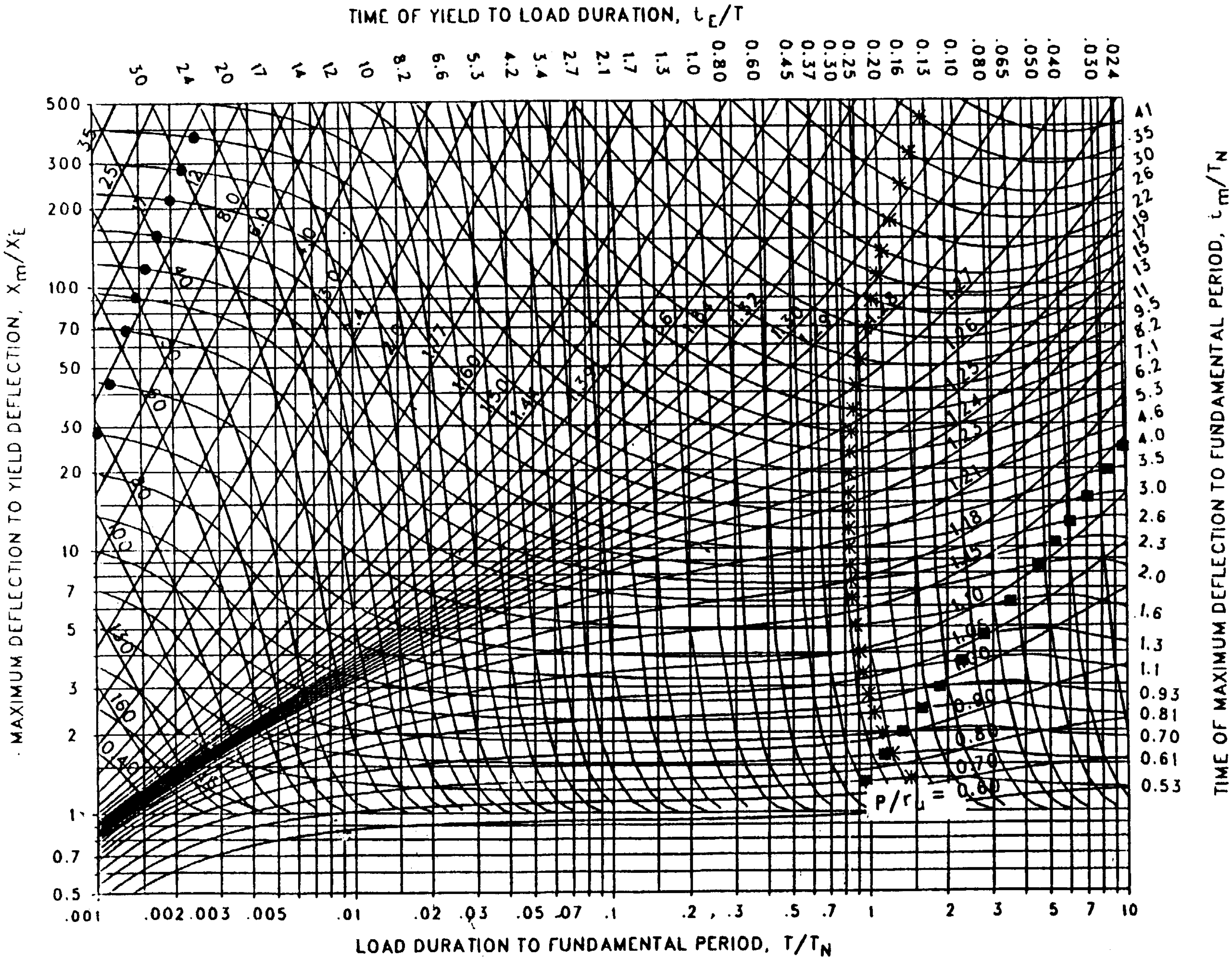


Figure 3-176 Maximum response of elasto-plastic, one-degree-of-freedom system for bilindar-triangular pulse (C_1 = 0.787, C_2 = 300.)

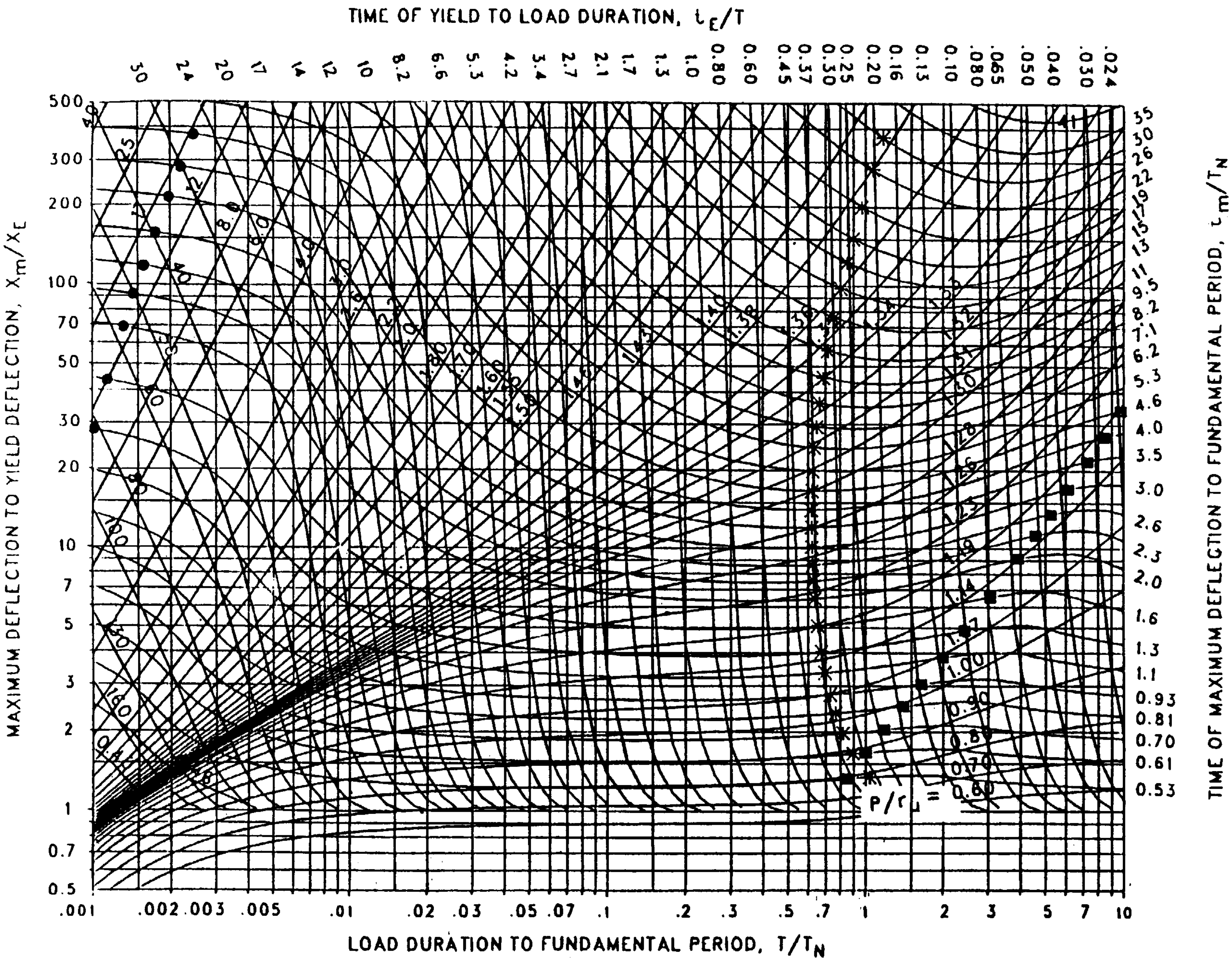


Figure 3-177 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.750, C_2 = 300.)

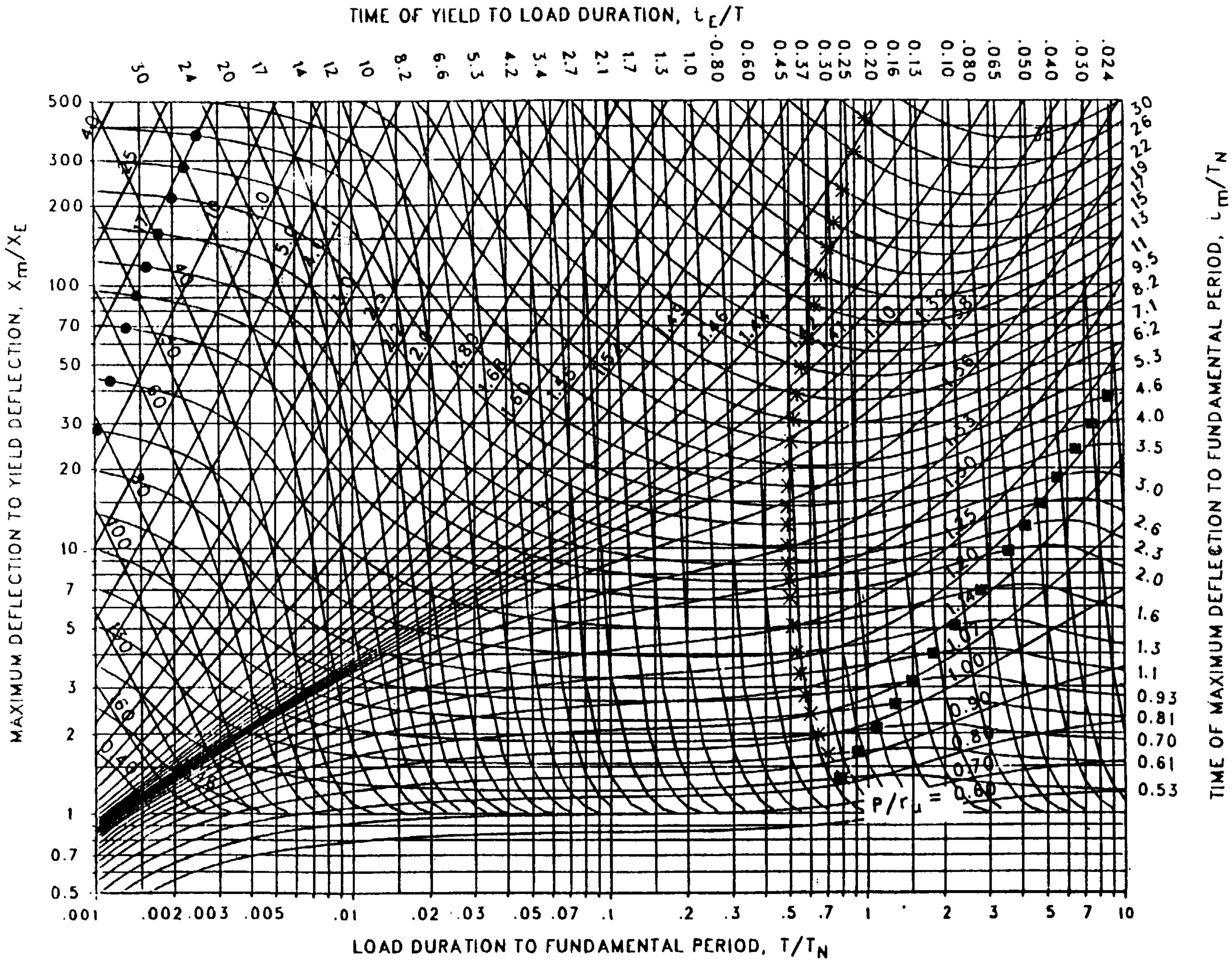


Figure 3-178 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.715, C_2 = 300.)

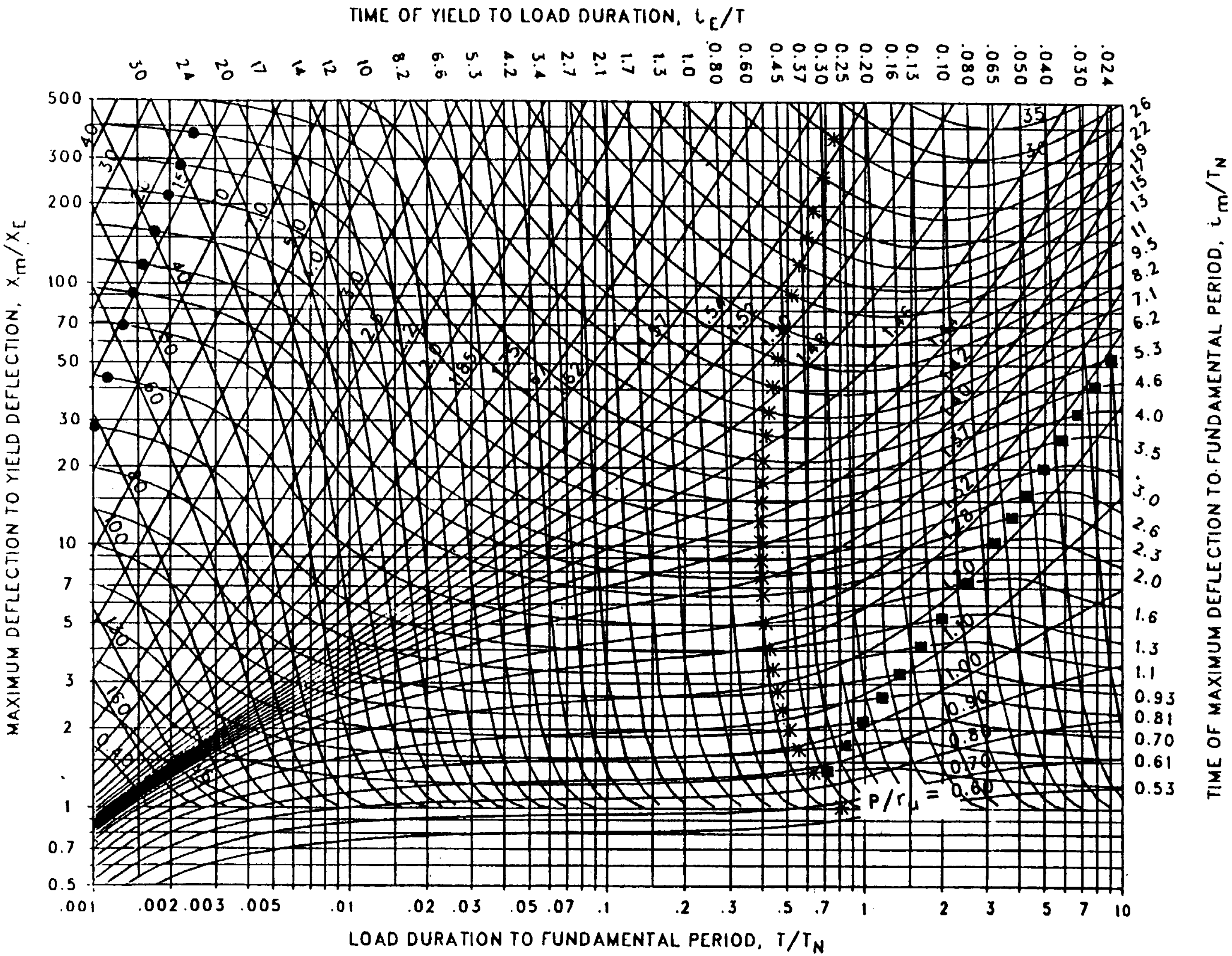


Figure 3-179 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.681, C_2 = 300.)

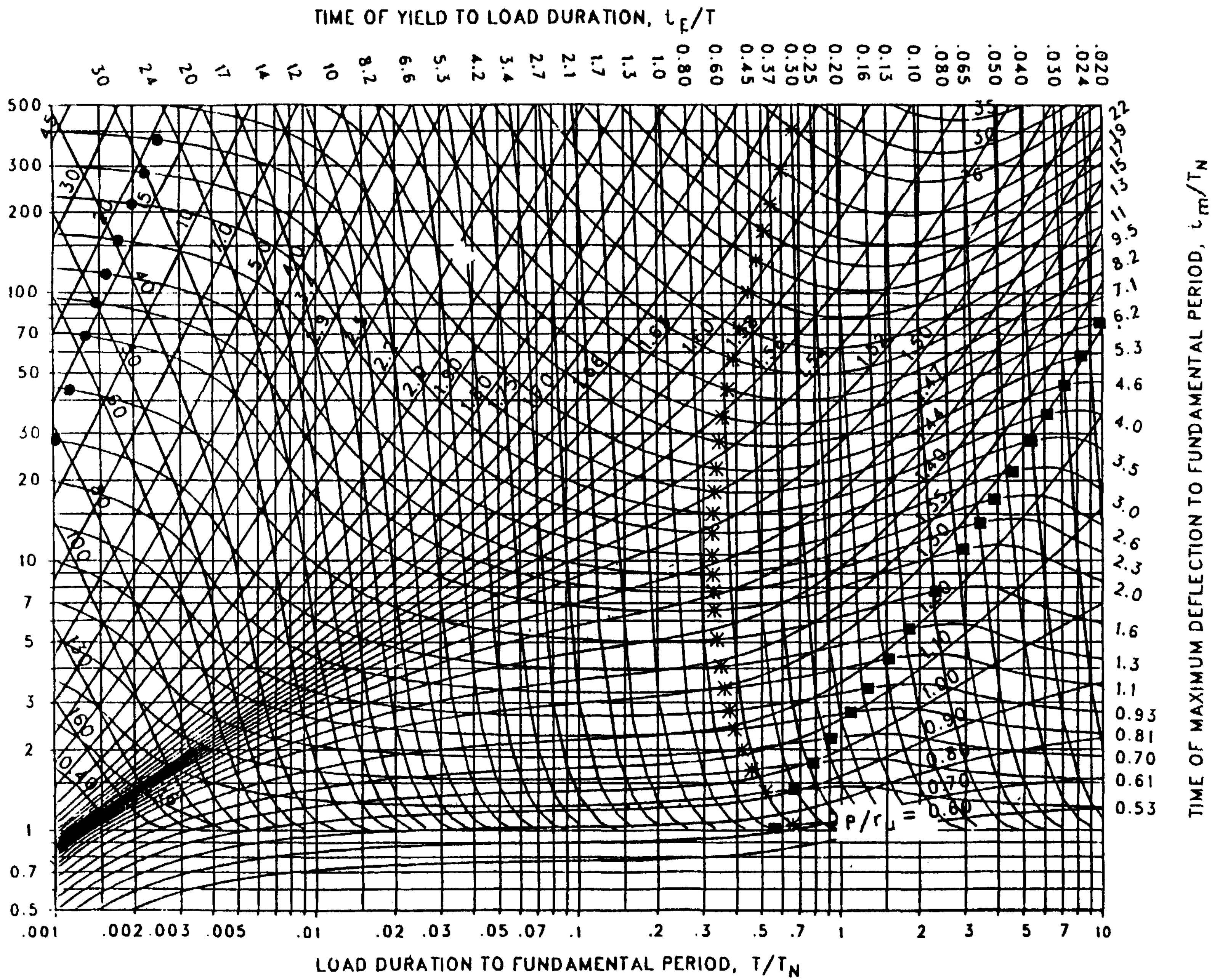


Figure 3-180 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.648, C_2 = 300.)

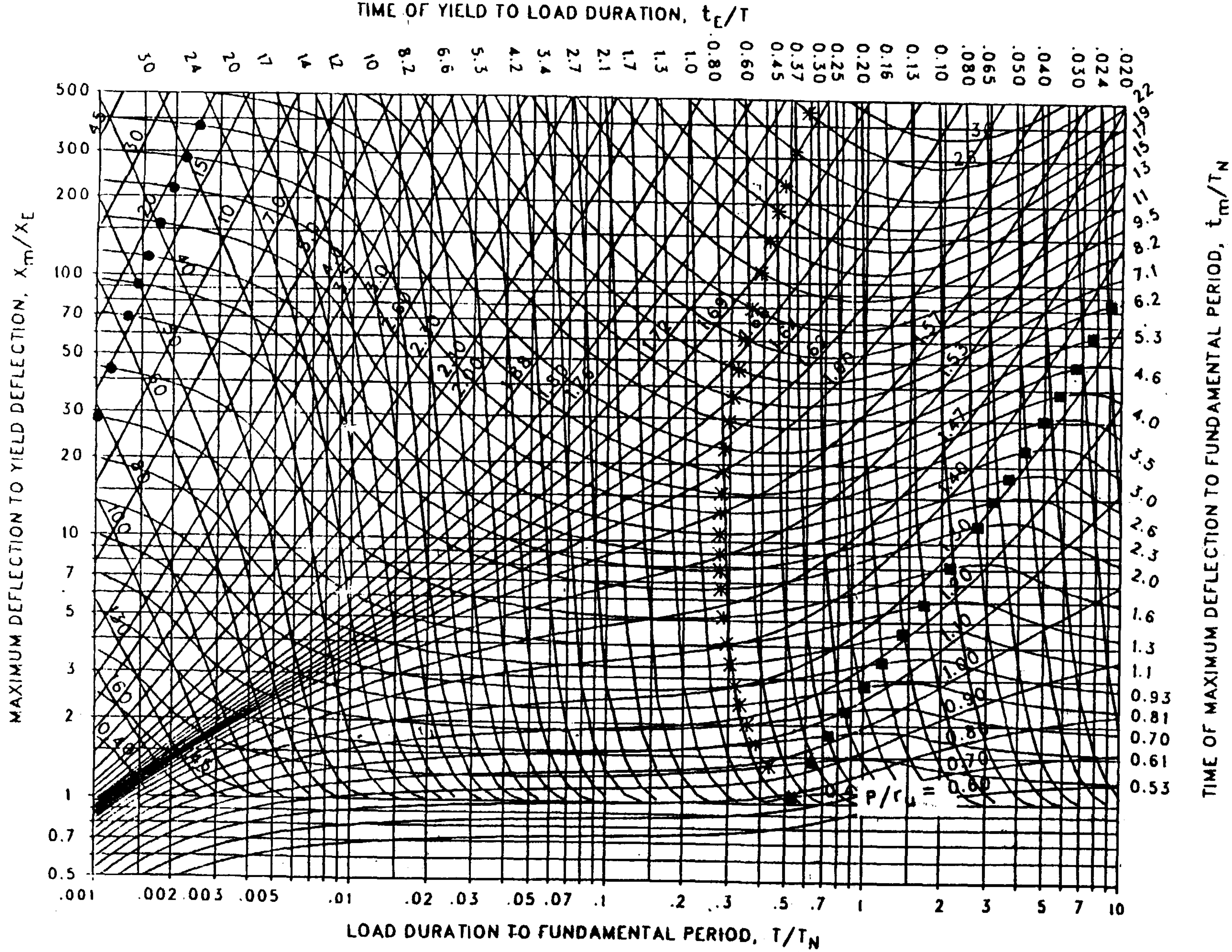


Figure 3-181 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.619, C_2 = 300.)

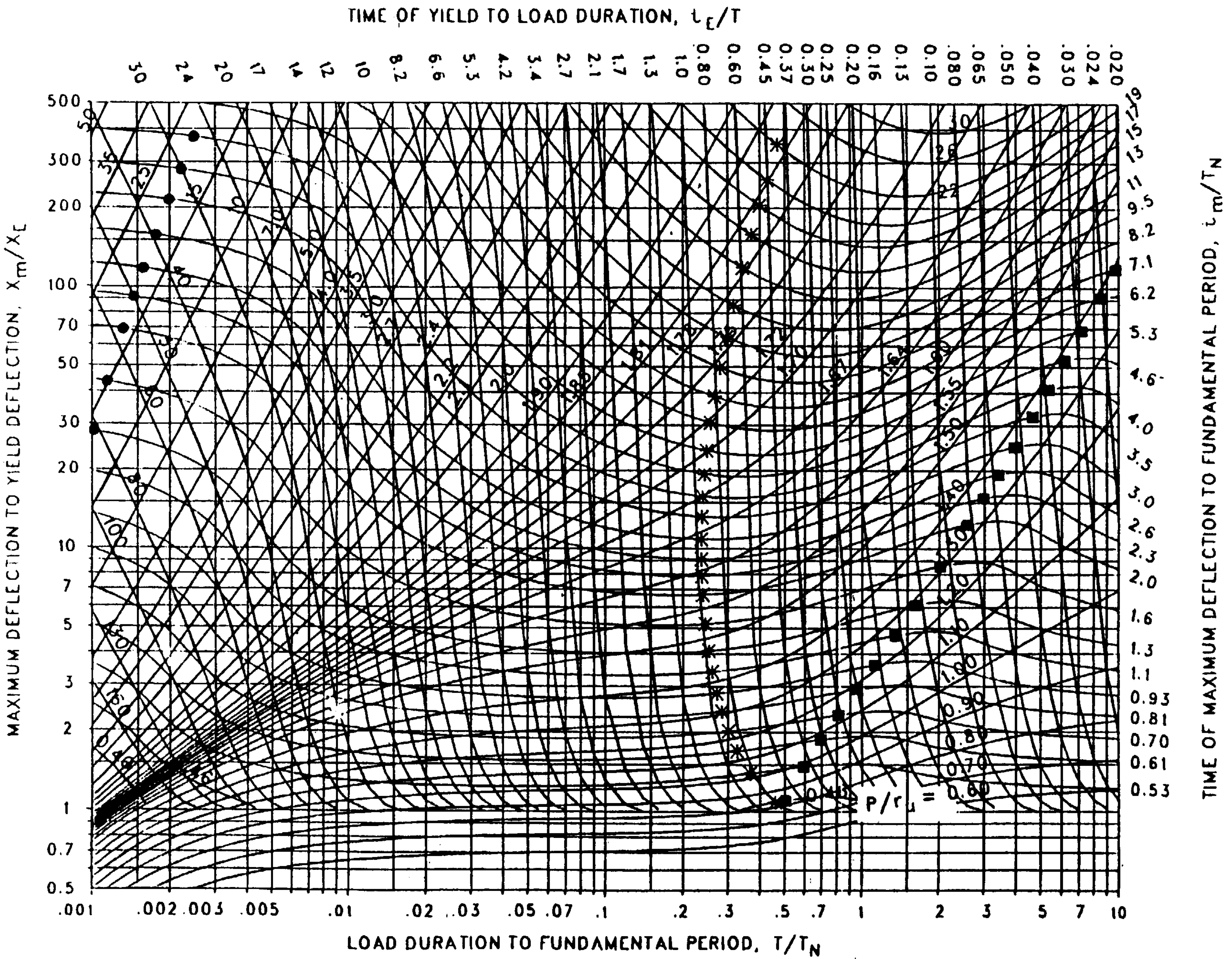


Figure 3-182 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.590, C_2 = 300.)

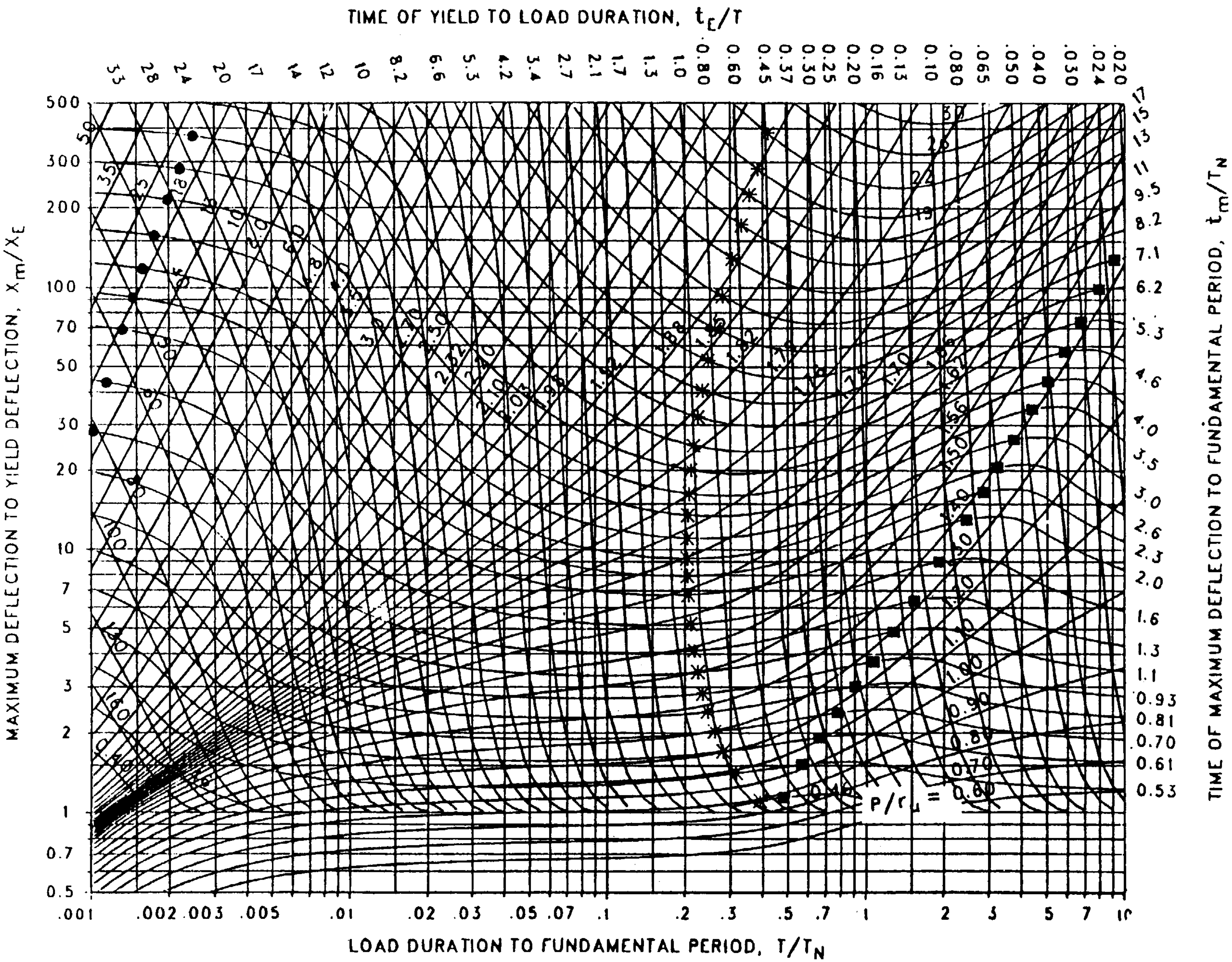


Figure 3-183 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.562, C_2 = 300.)

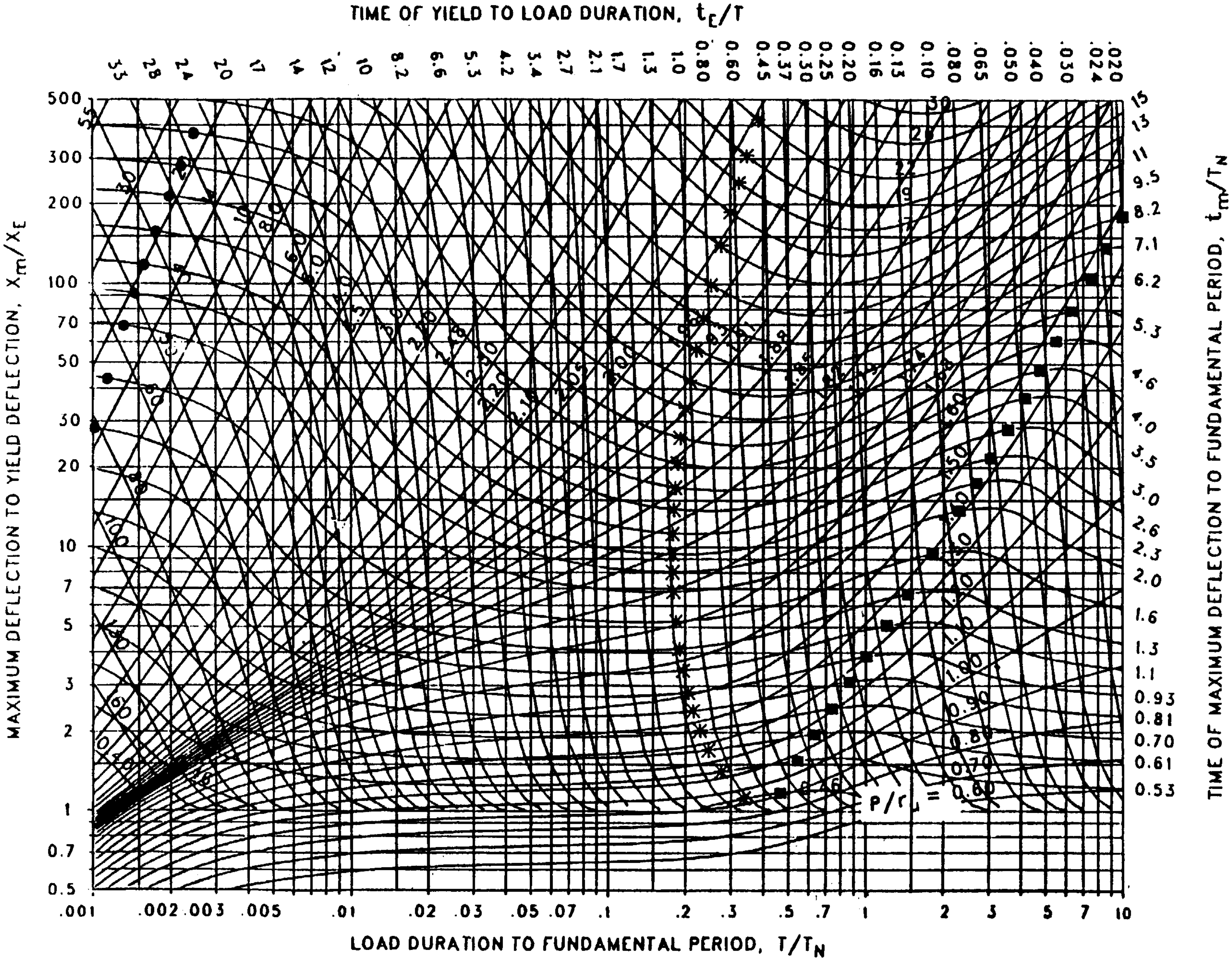


Figure 3-184 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.536, C_2 = 300.)

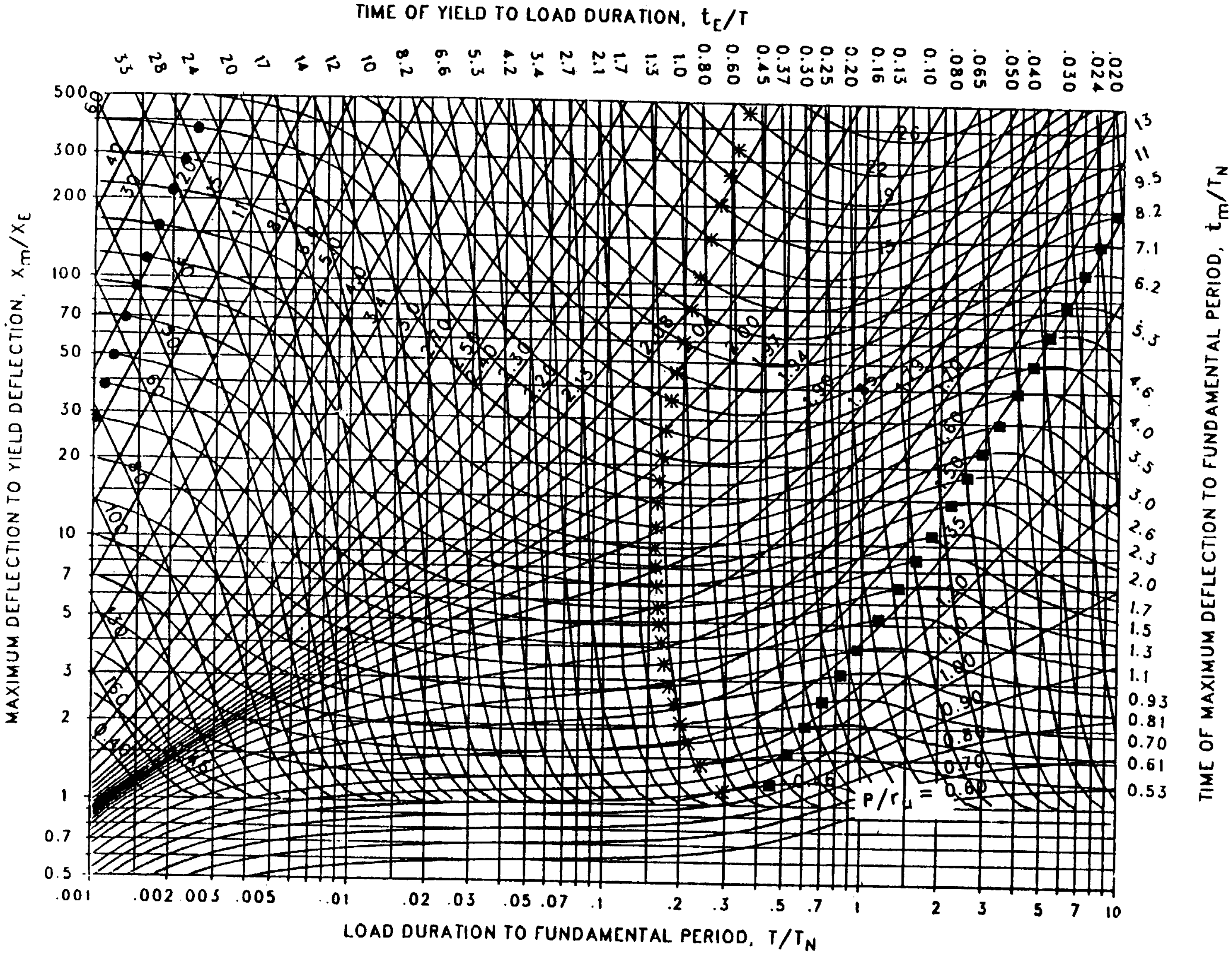


Figure 3-185 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.511, C_2 = 300.)

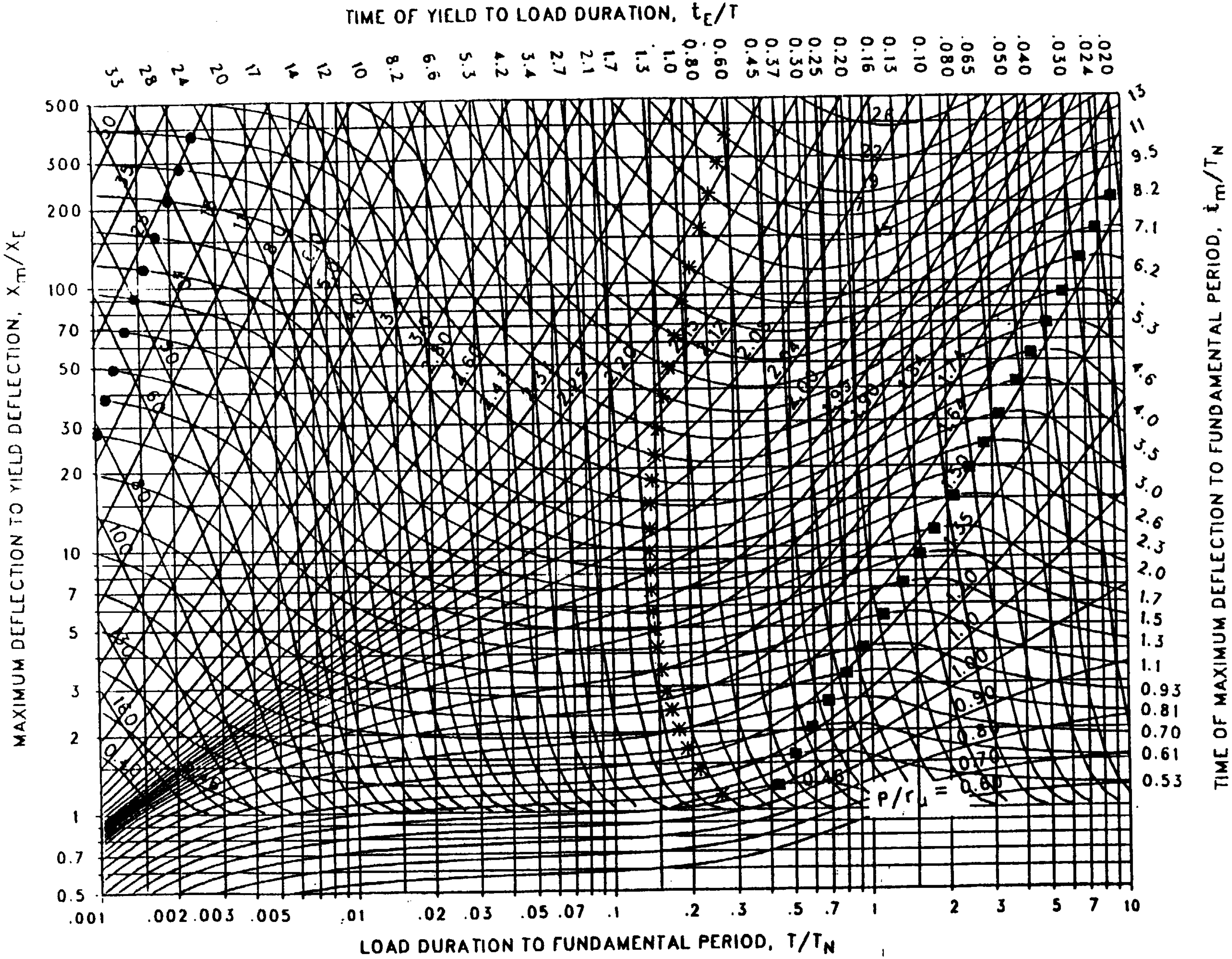


Figure 3-186 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.487, C_2 = 300.)

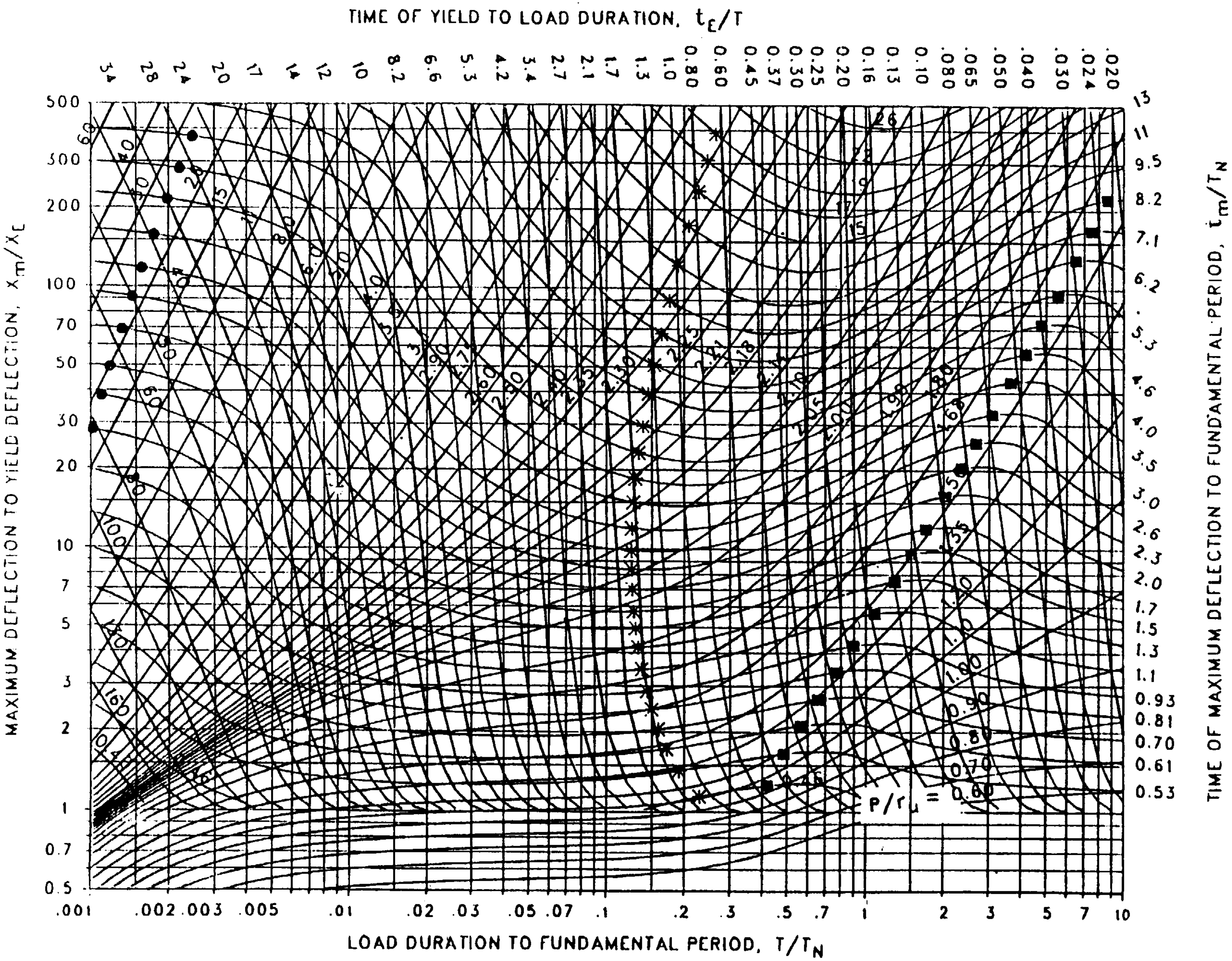


Figure 3-187 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.464, C_2 = 300.)

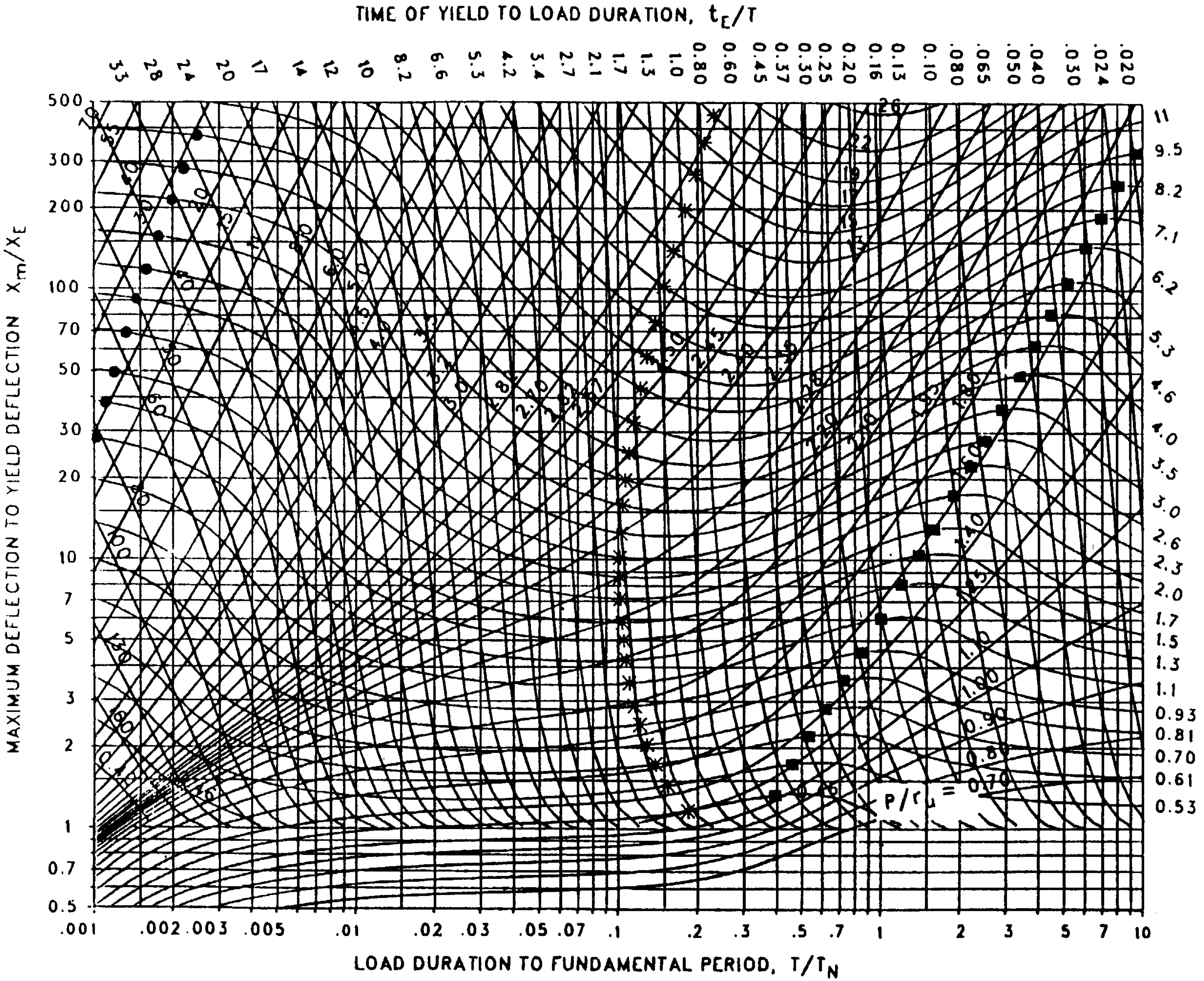


Figure 3-188 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.422, C_2 = 300.)

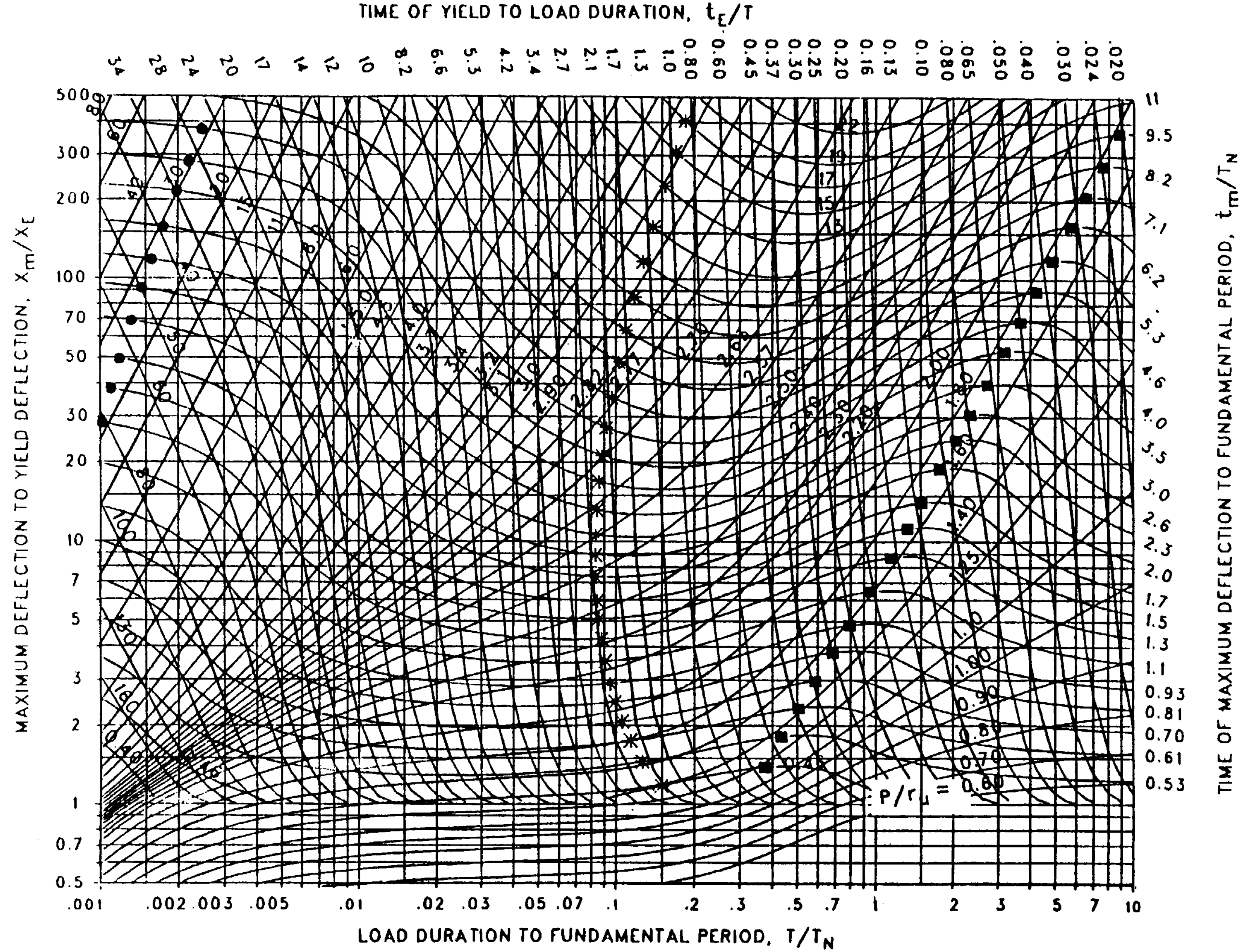


Figure 3-189 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.383, C_2 = 300.)

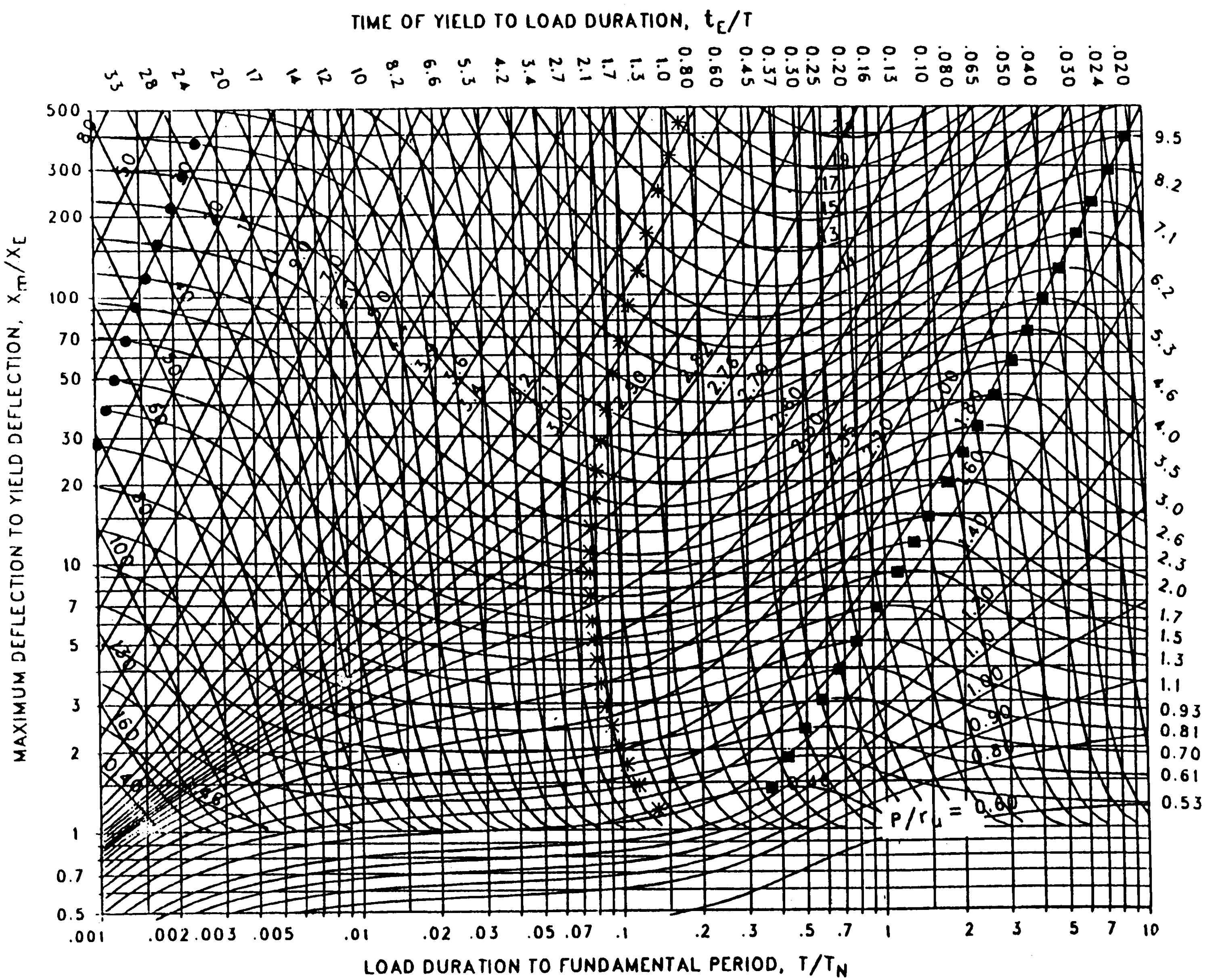


Figure 3-190 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.365, C_2 = 300.)

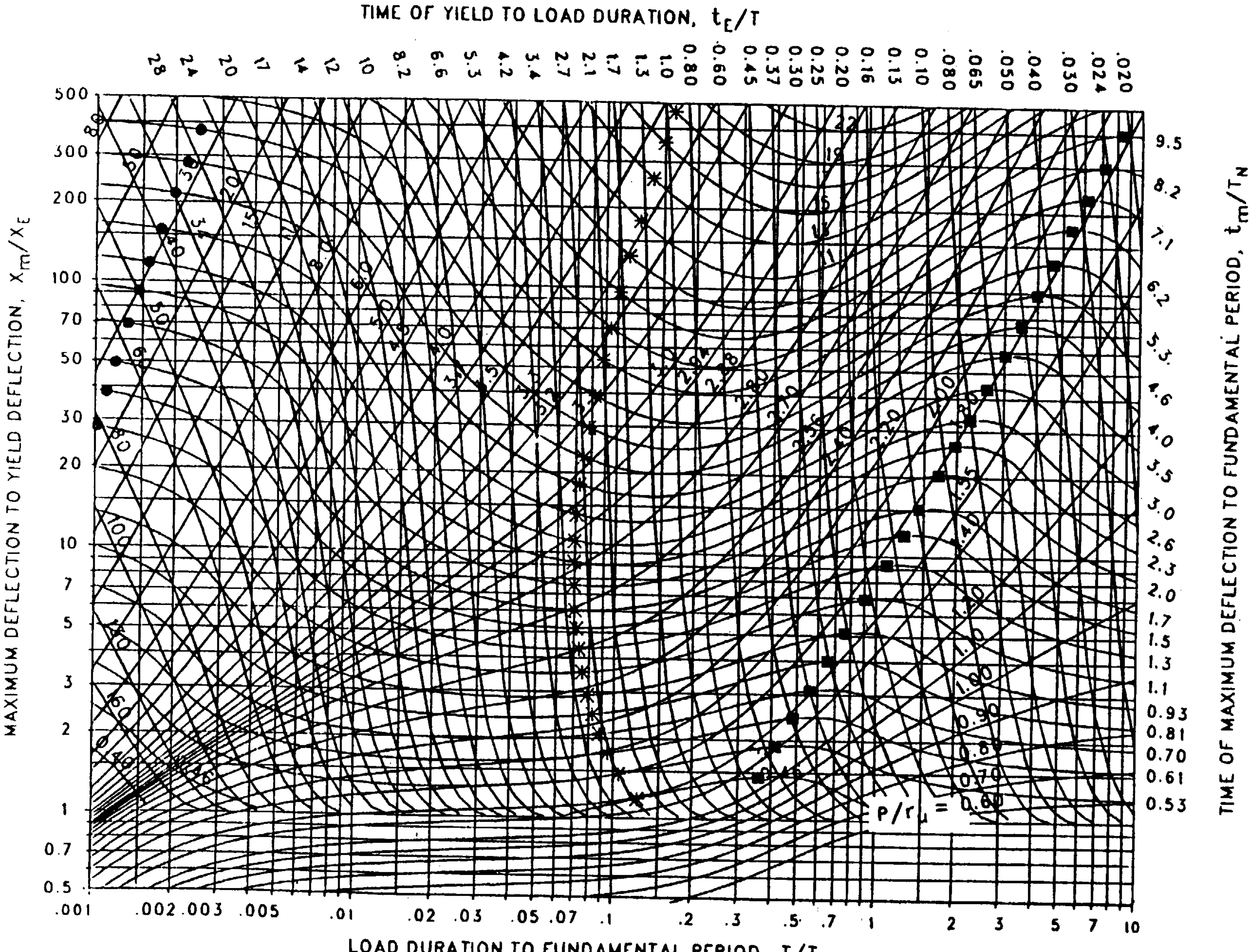


Figure 3-191 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.348, C_2 = 300.)

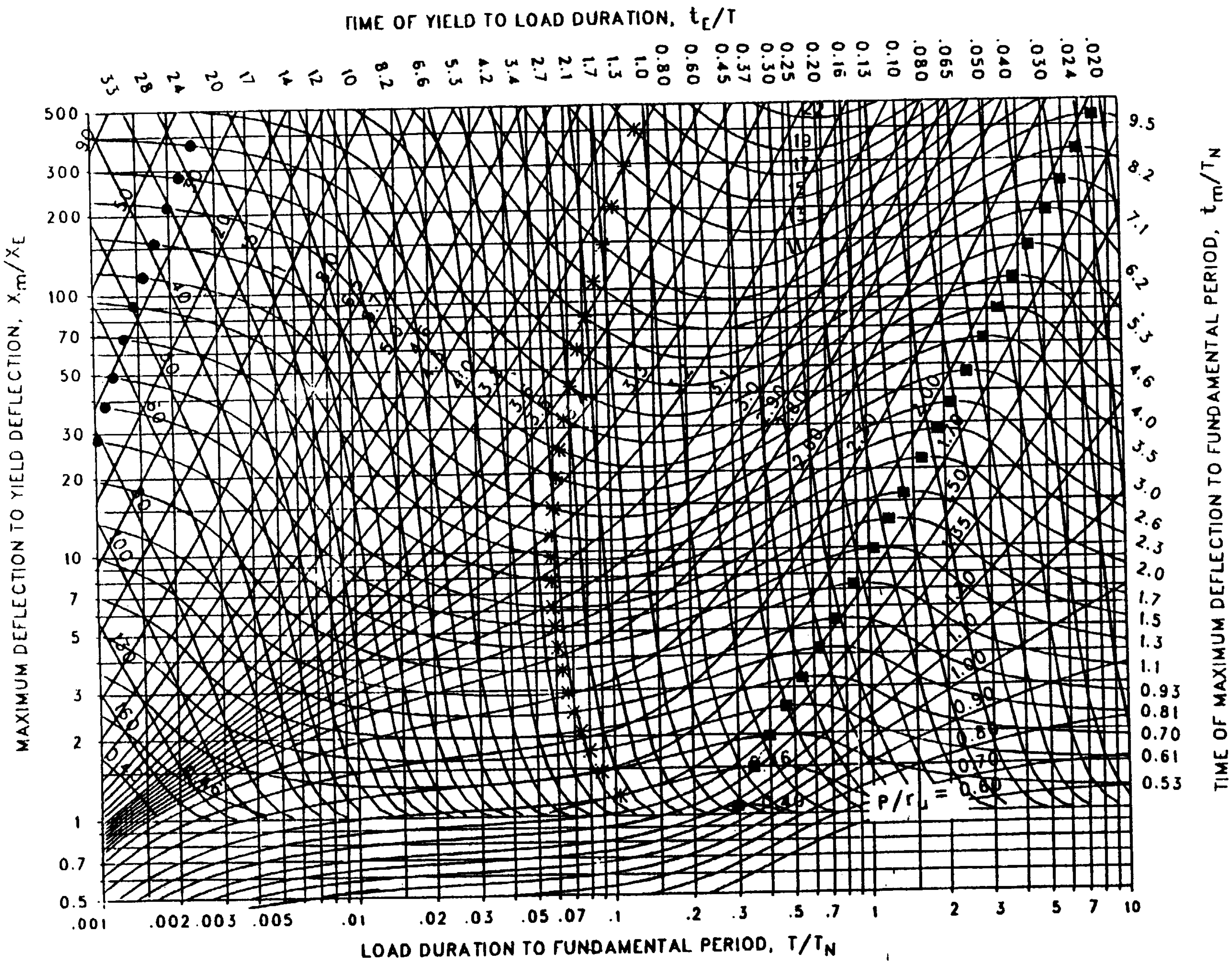


Figure 3-192 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.316, C_2 = 300.)

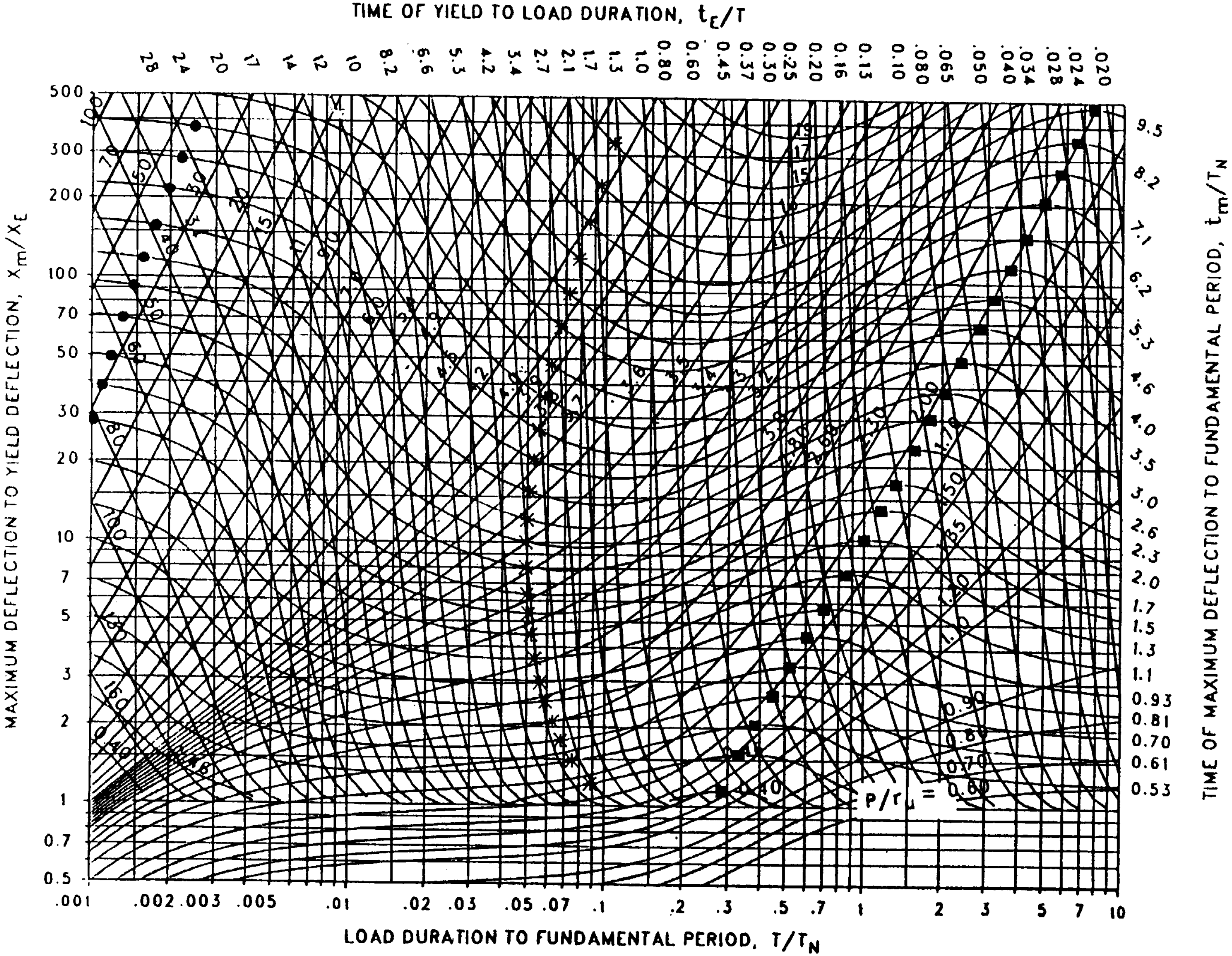


Figure 3-193 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.287, C_2 = 300.)

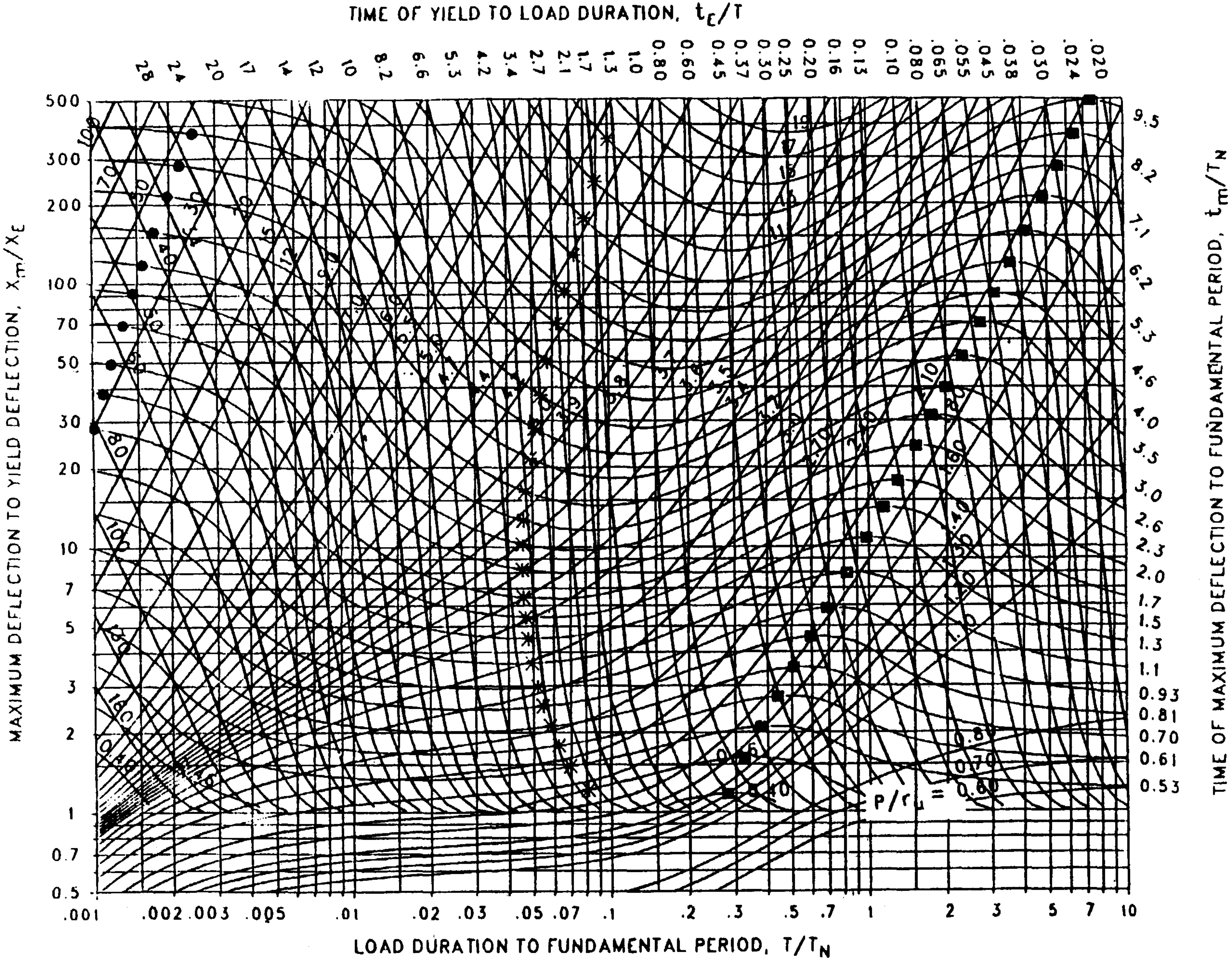


Figure 3-194 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.274, C_2 = 300.)

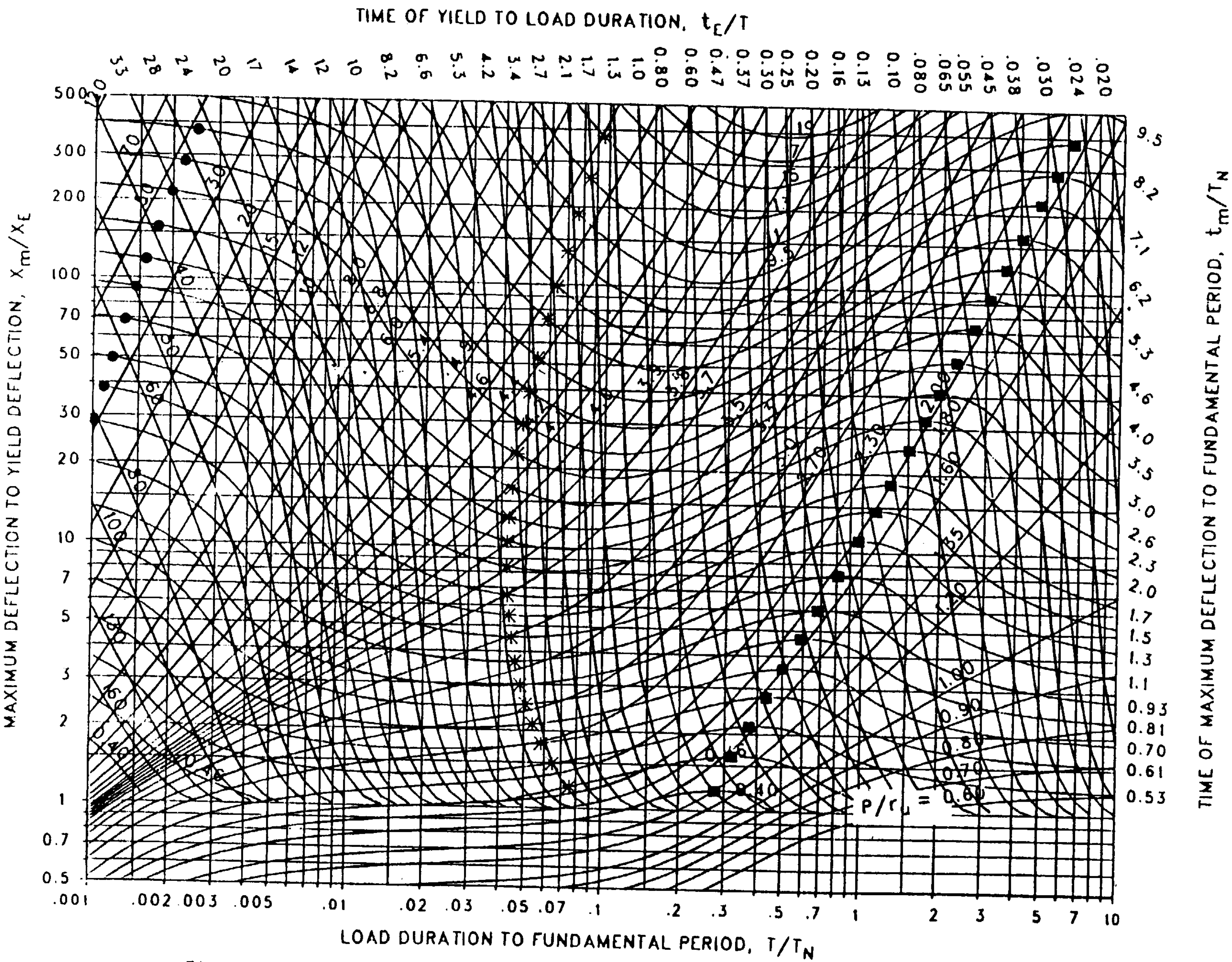


Figure 3-195 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.261, C_2 = 300.)

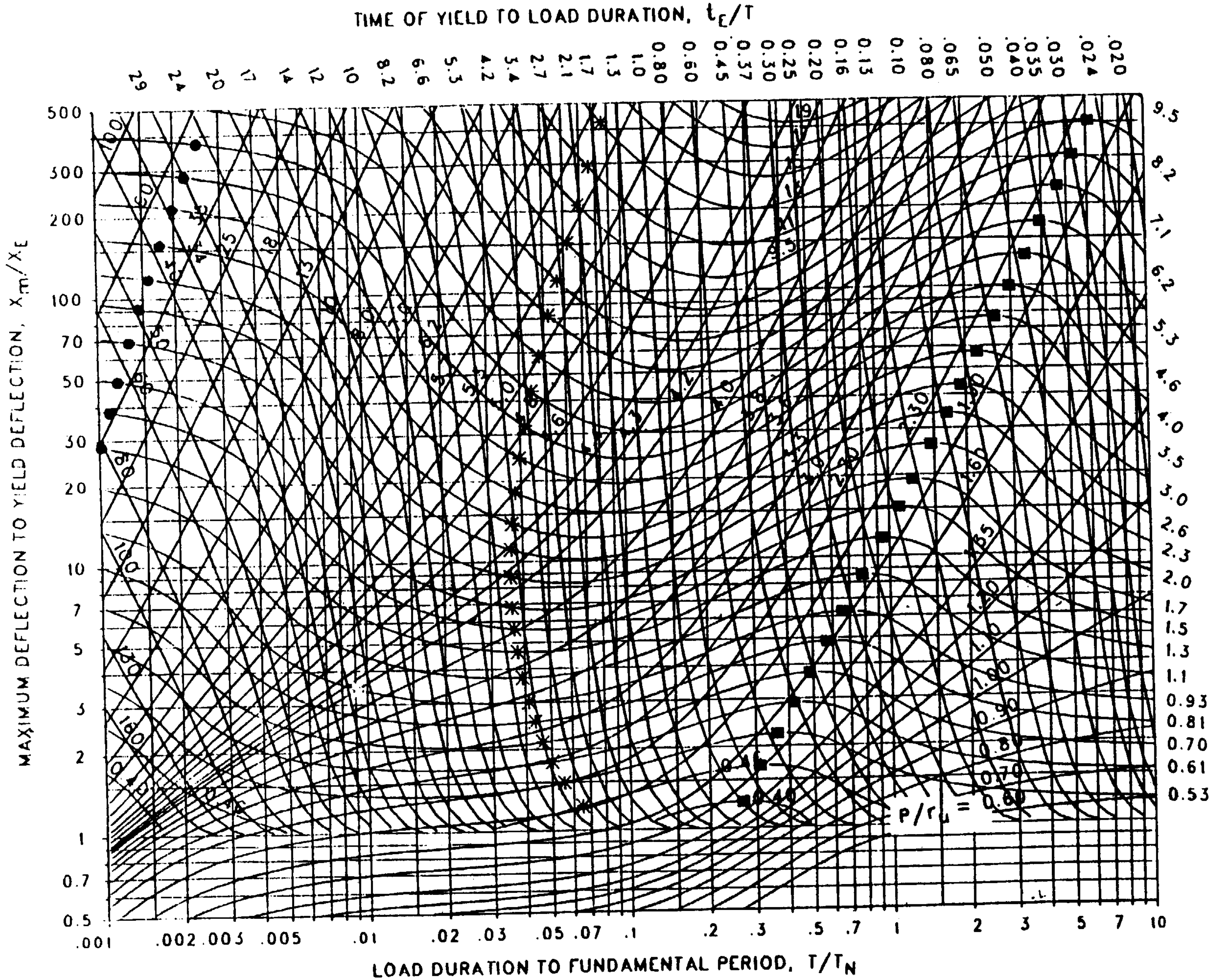


Figure 3-196 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.237, C_2 = 300.)

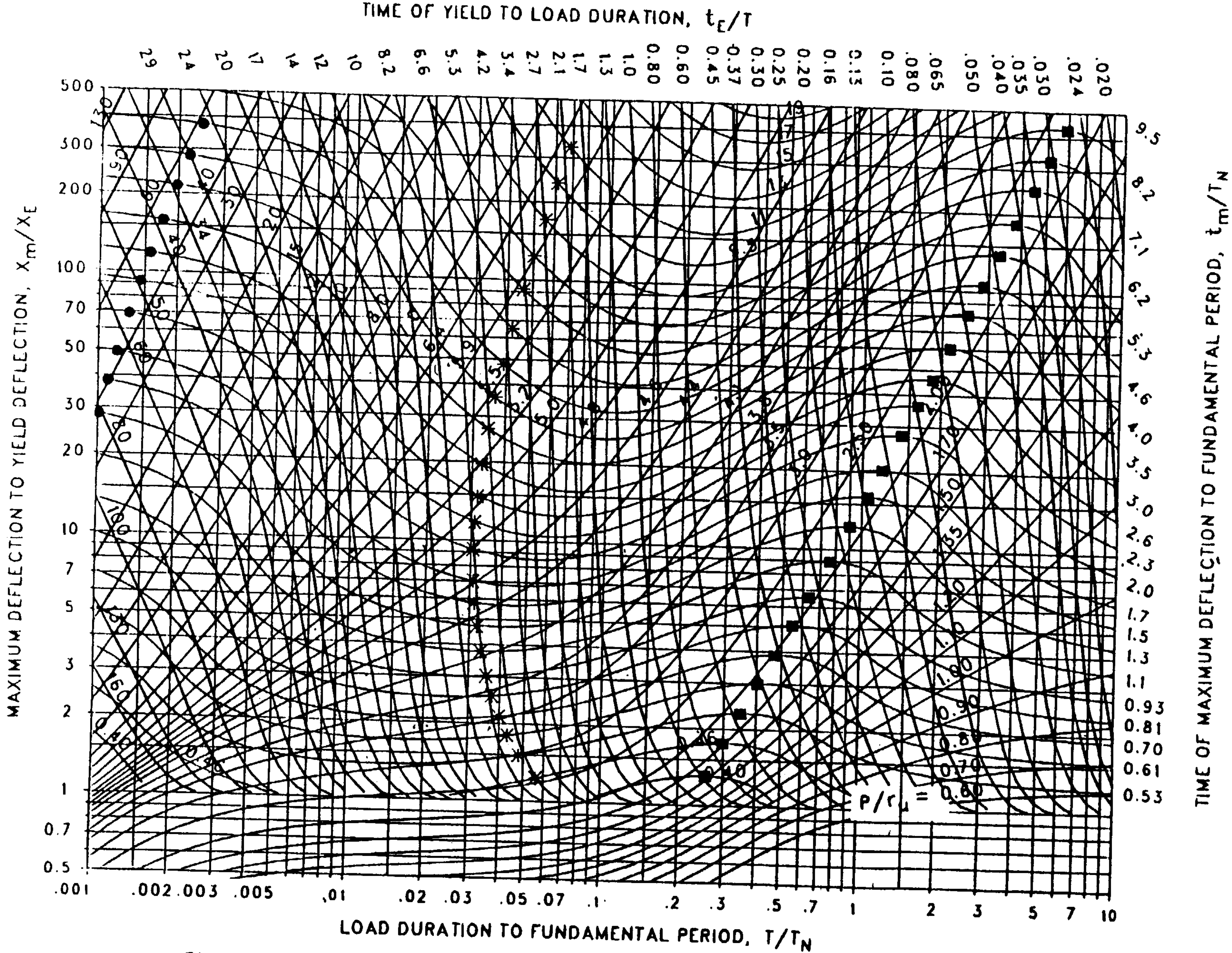


Figure 3-197 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.215, C_2 = 300.)

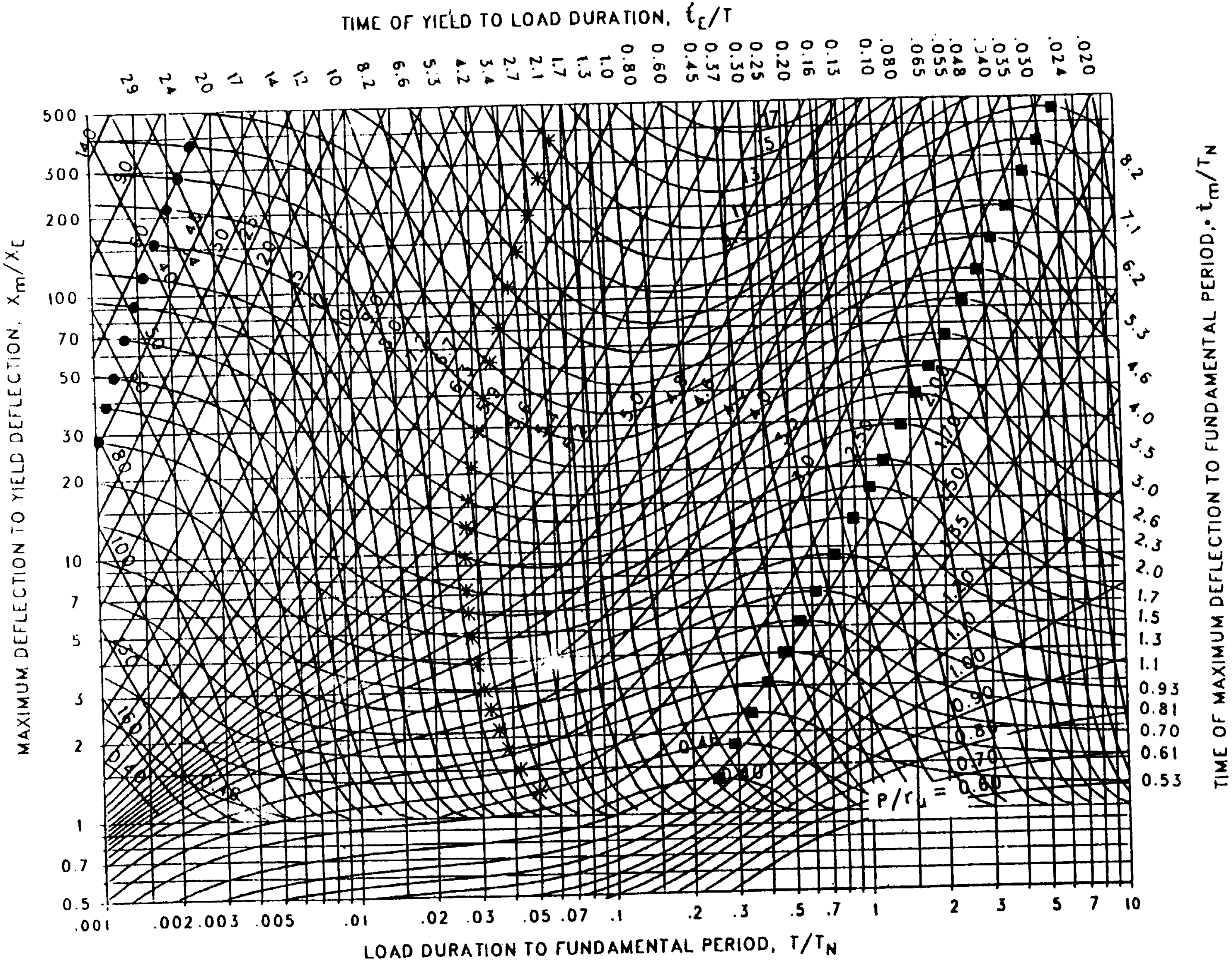


Figure 3-198 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.198, C_2 = 300.)

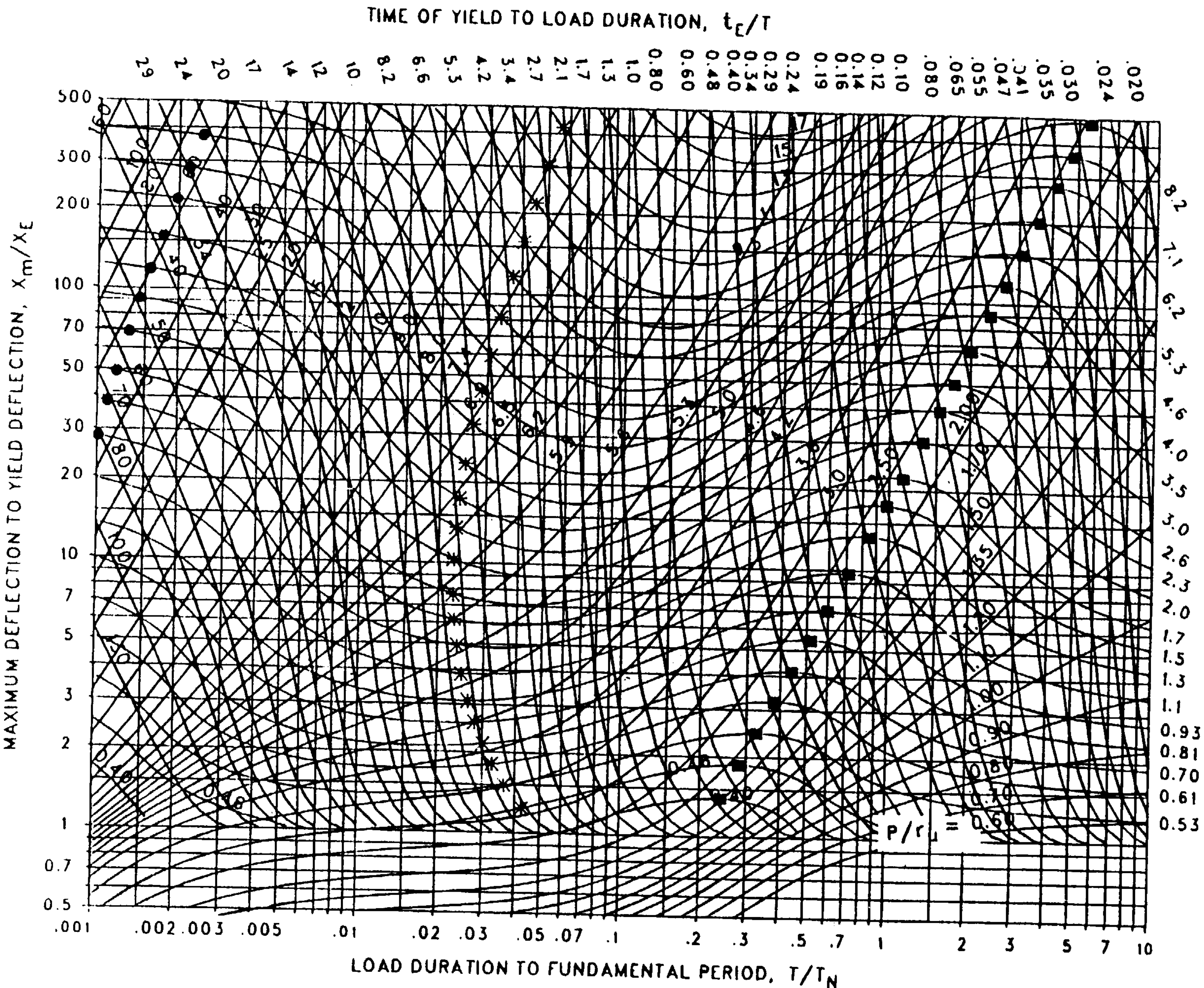


Figure 3-199 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.178, C_2 = 300.)

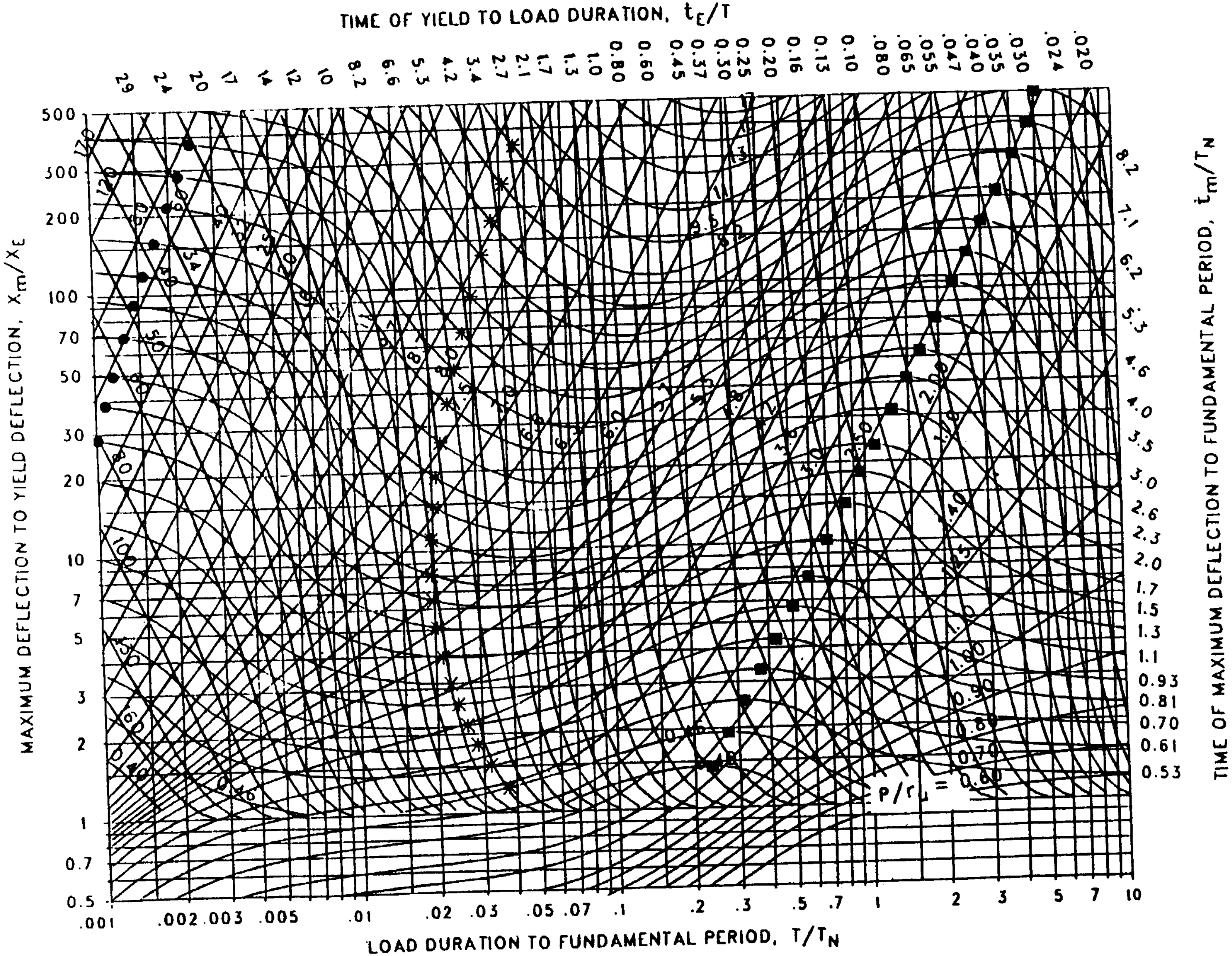


Figure 3-200 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.162, C_2 = 300.)

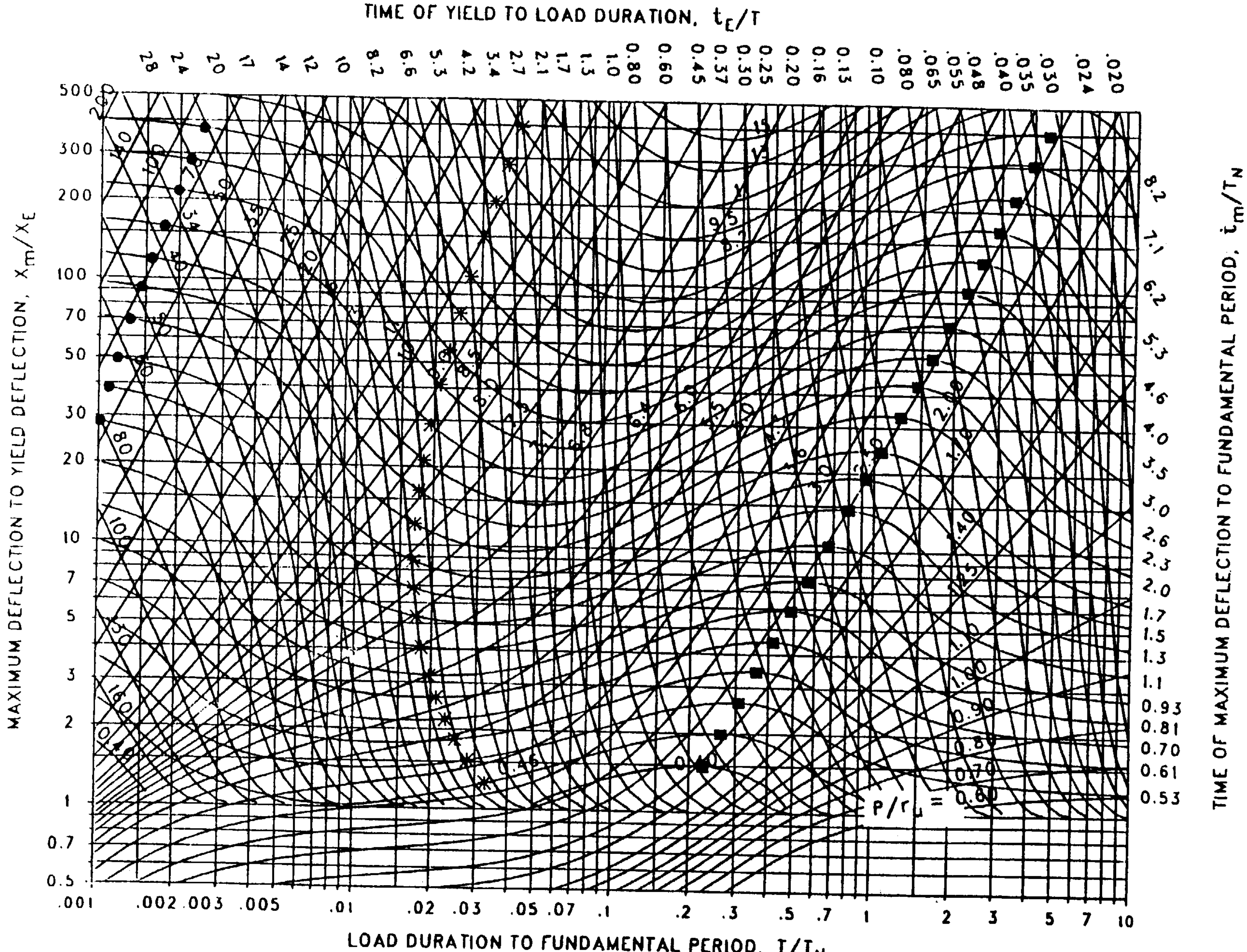


Figure 3-201 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.147, C_2 = 300.)

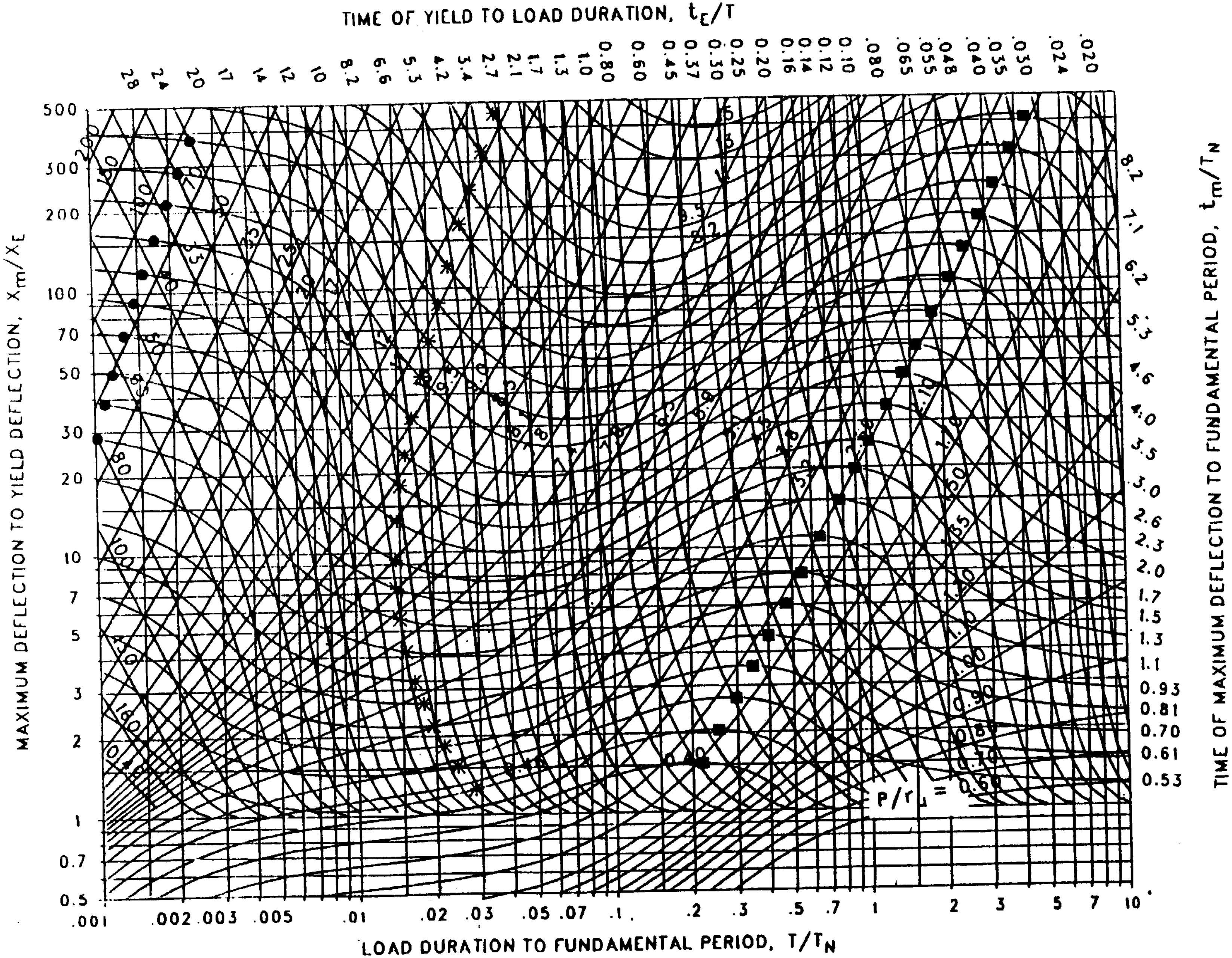


Figure 3-202 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.133, C_2 = 300.)

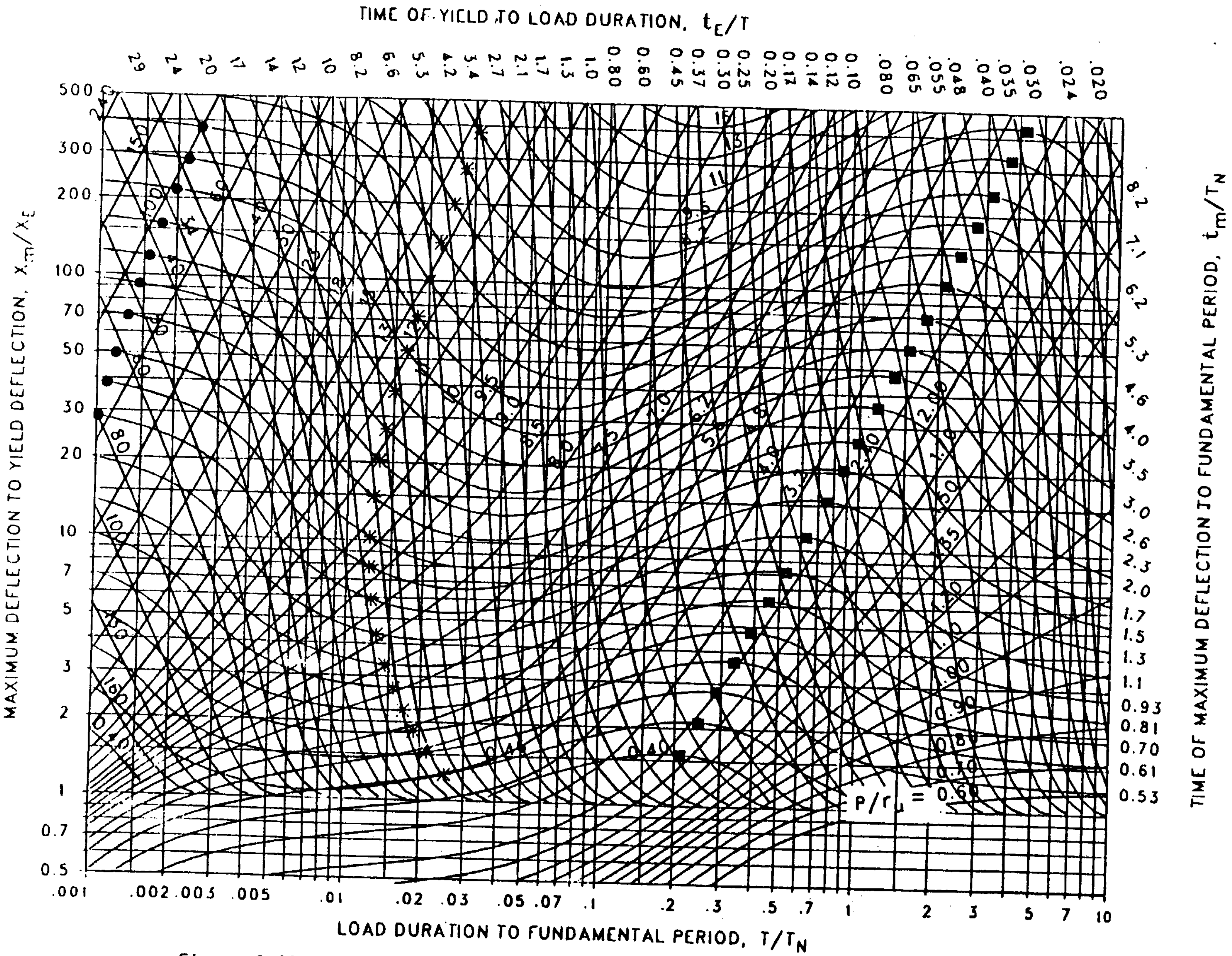


Figure 3-203 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.121, C_2 = 300.)

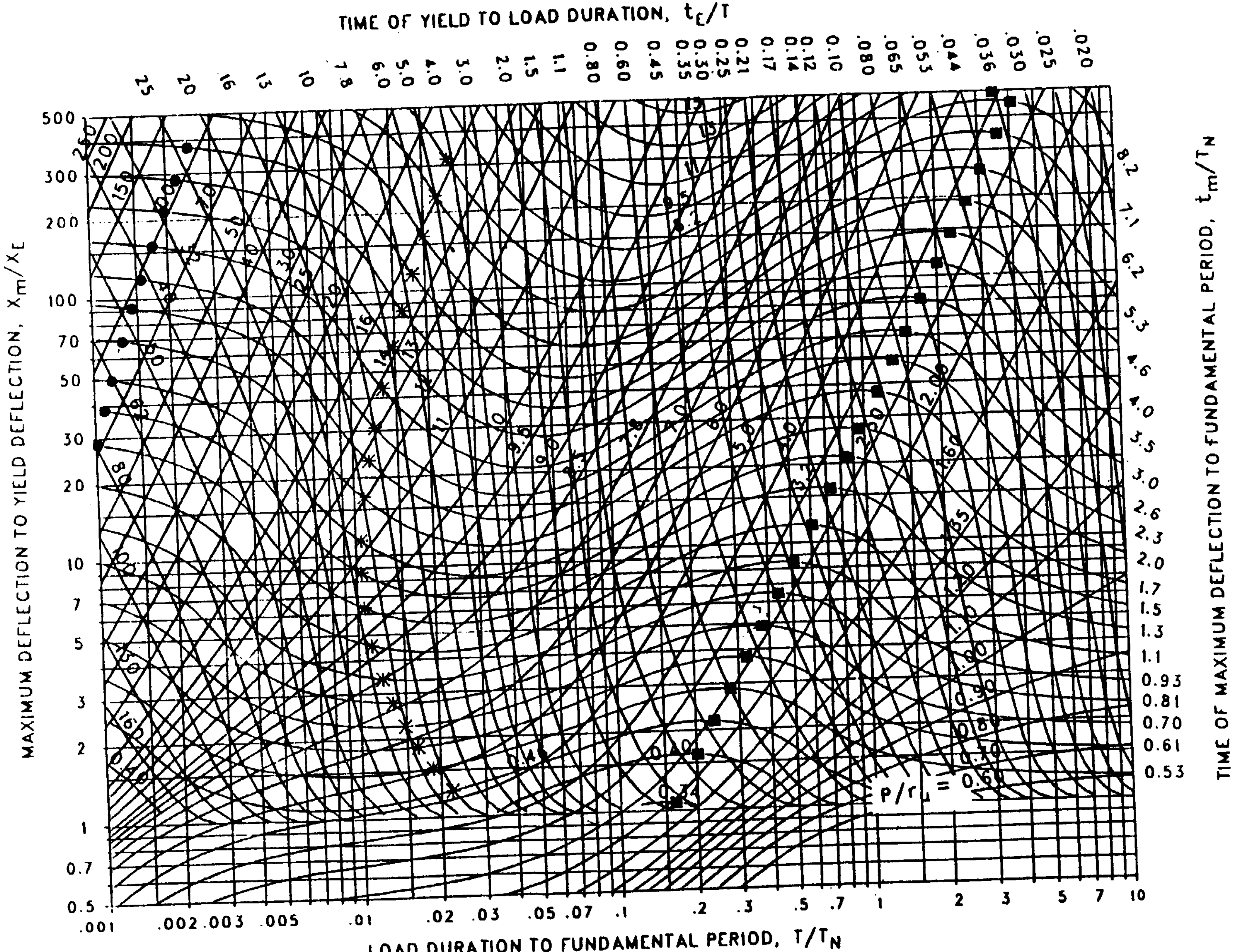


Figure 3-204 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.110, C_2 = 300.)

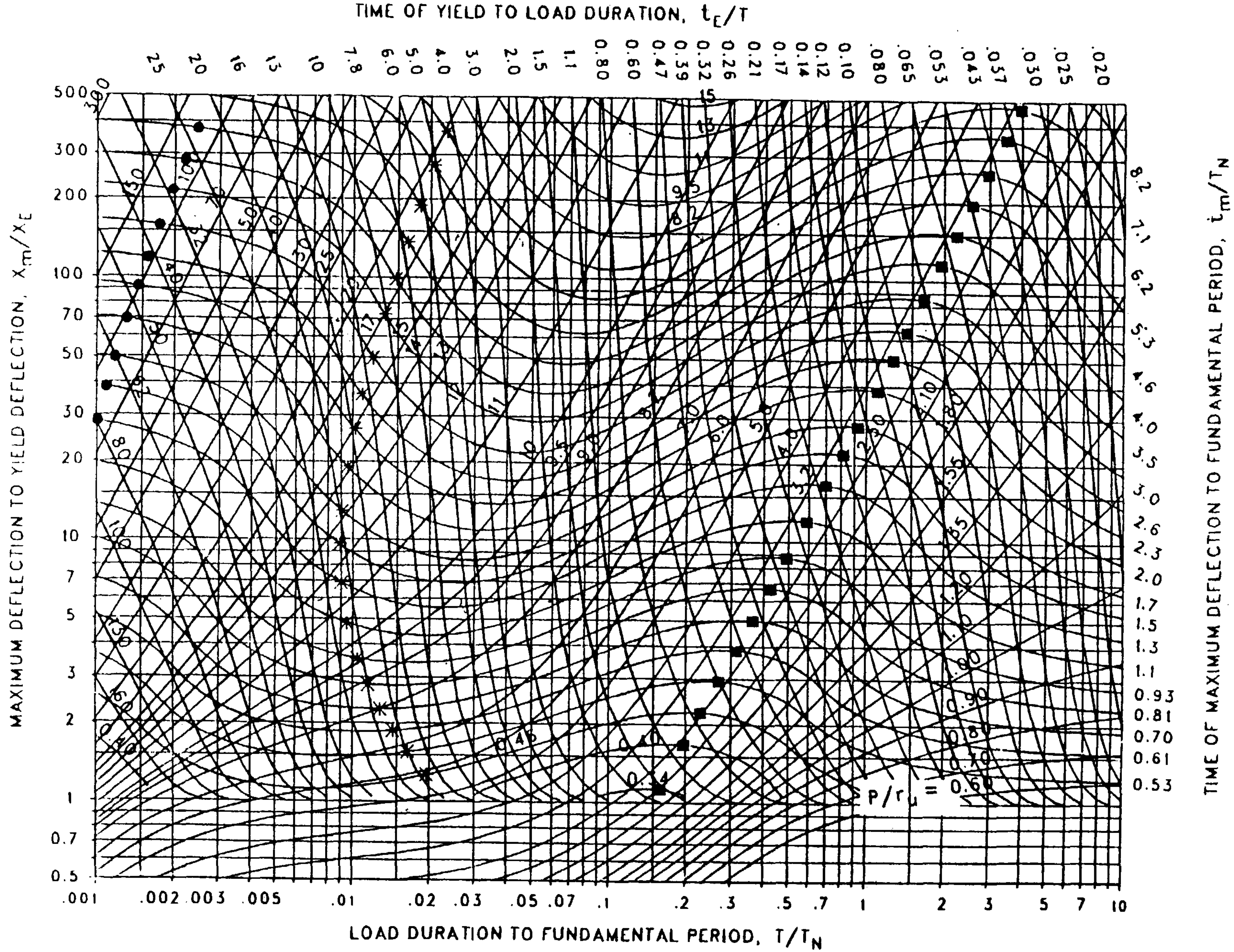


Figure 3-205 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.100, C_2 = 300.)

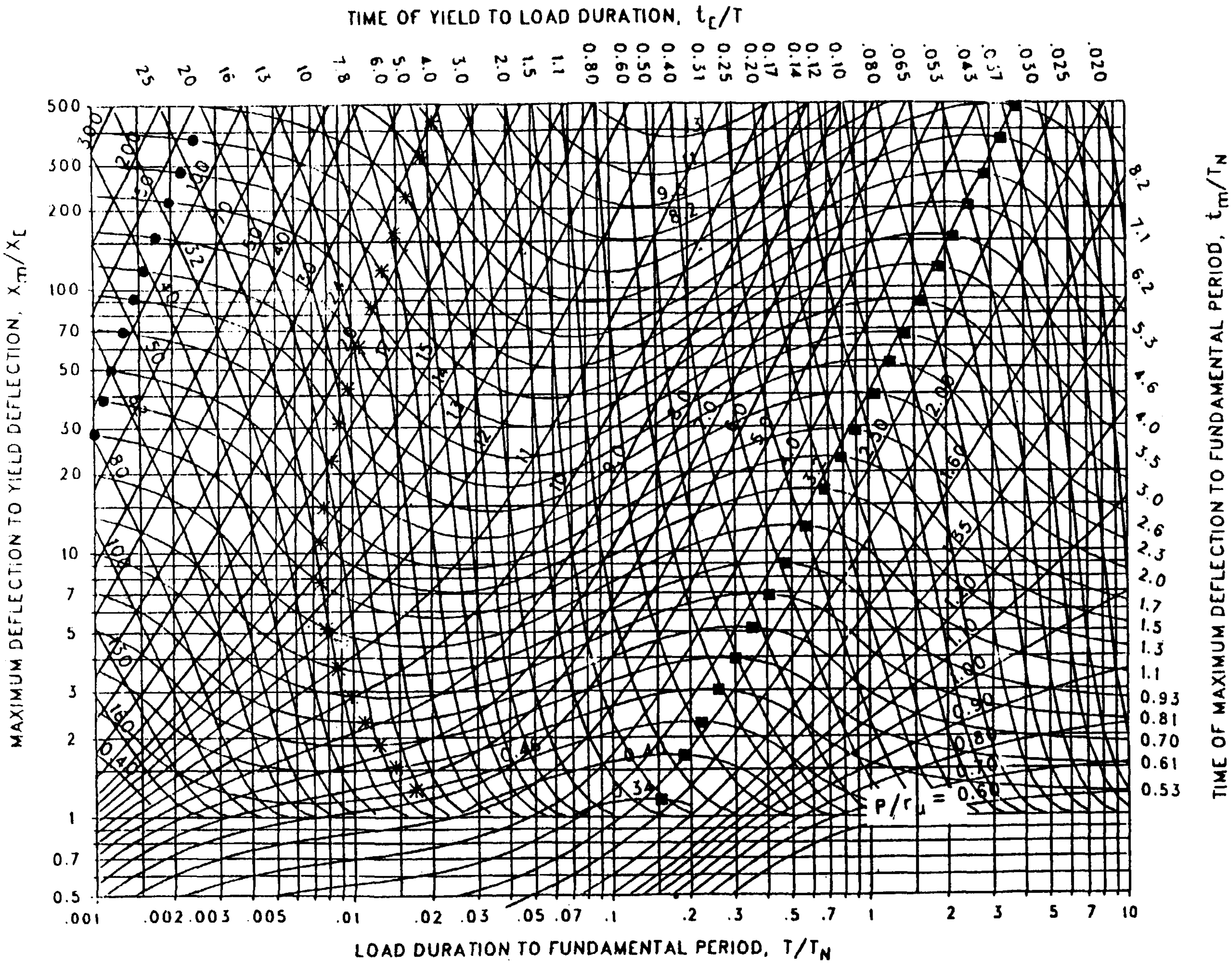


Figure 3-206 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.091, C_2 = 300.)

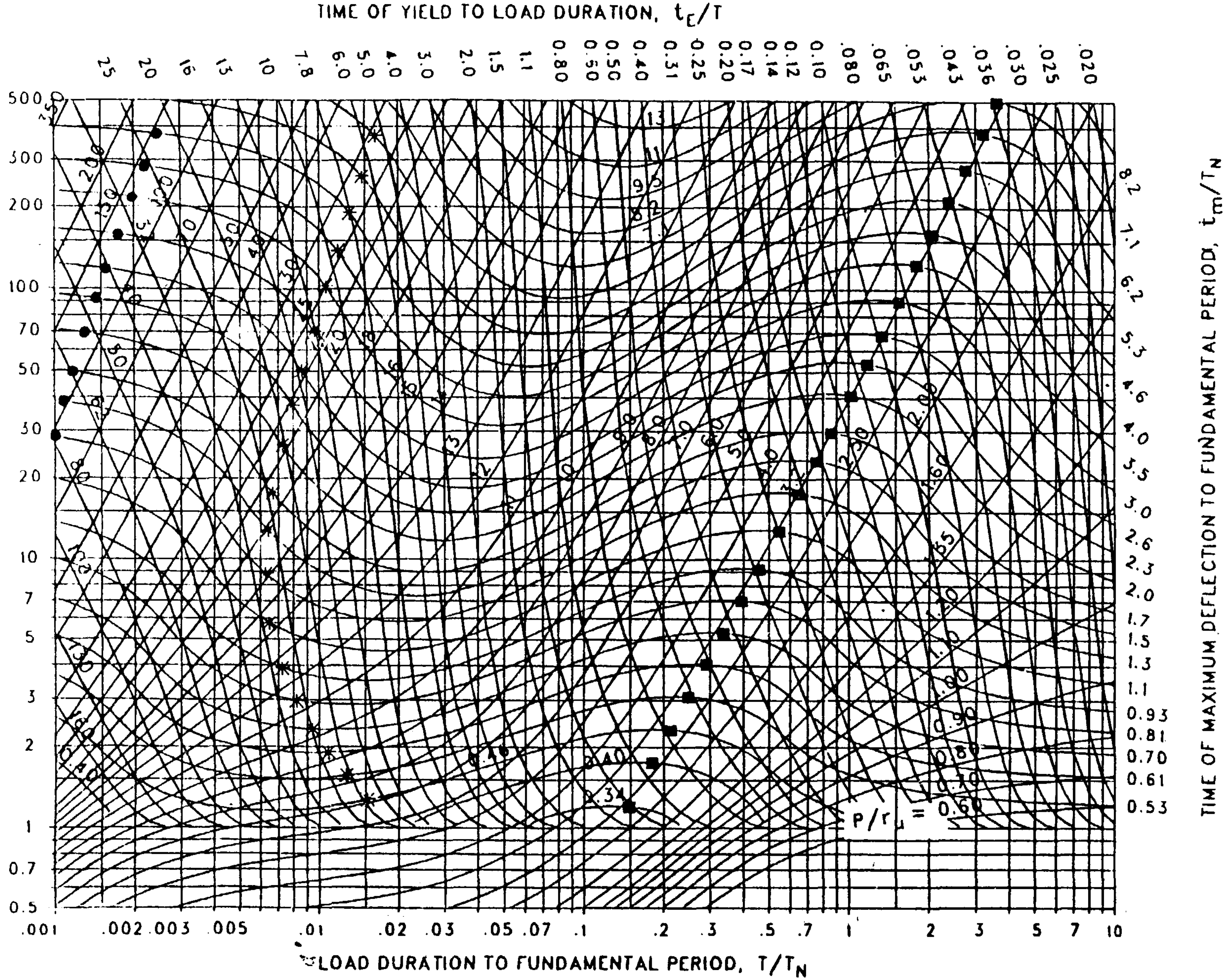


Figure 3-207 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.083, C_2 = 300.)

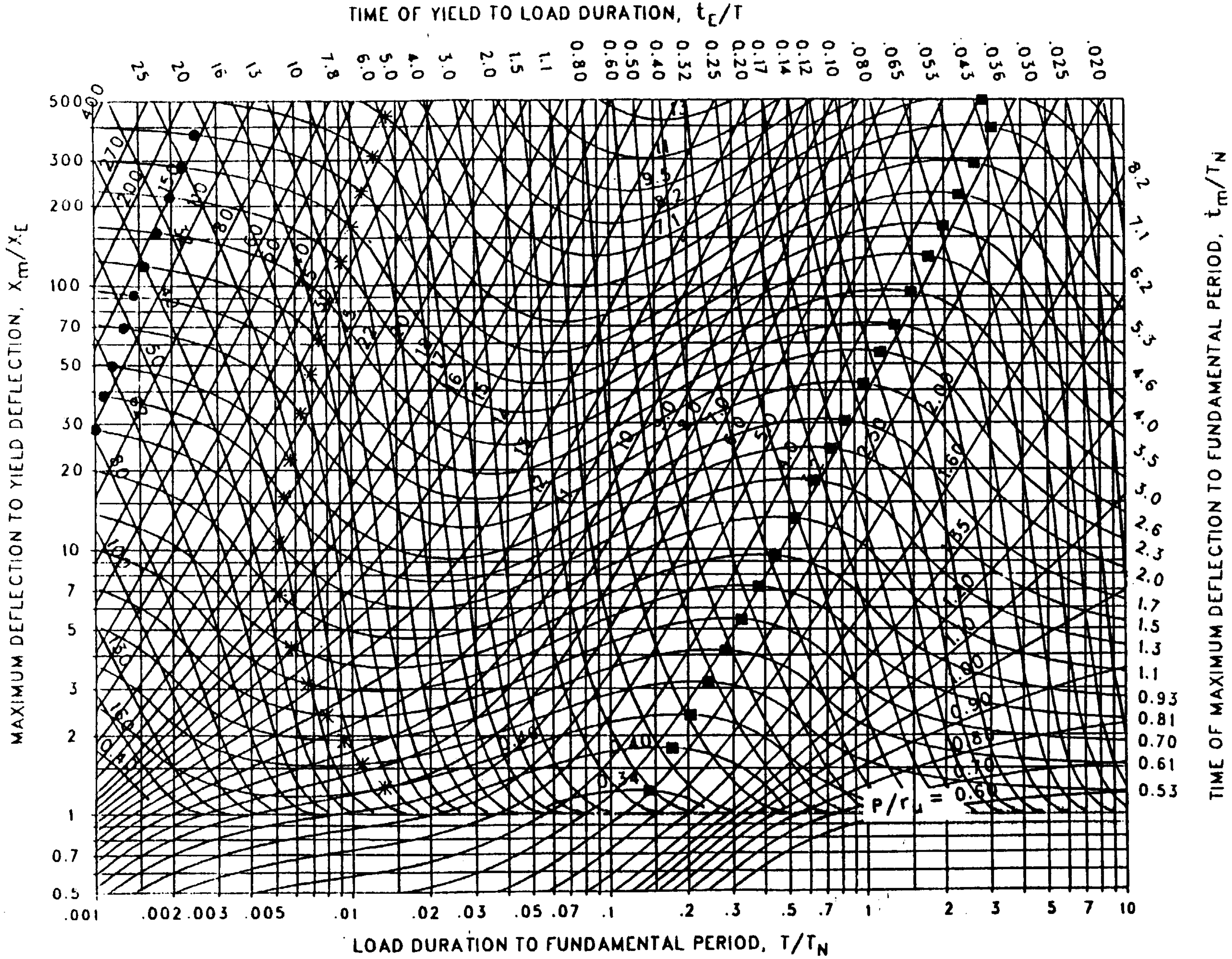


Figure 3-208 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.075, C_2 = 300.)

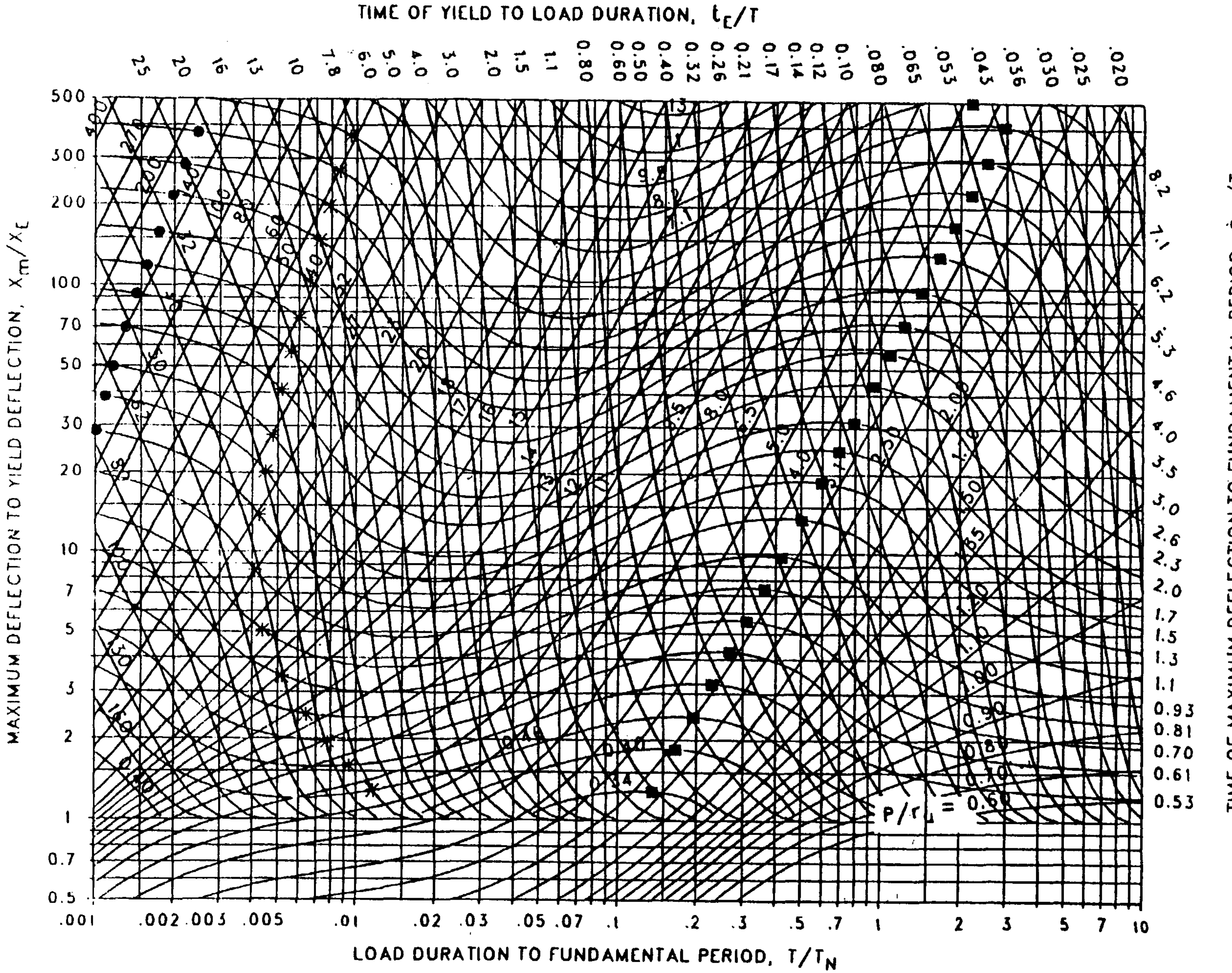


Figure 3-209 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.068, C_2 = 300.)

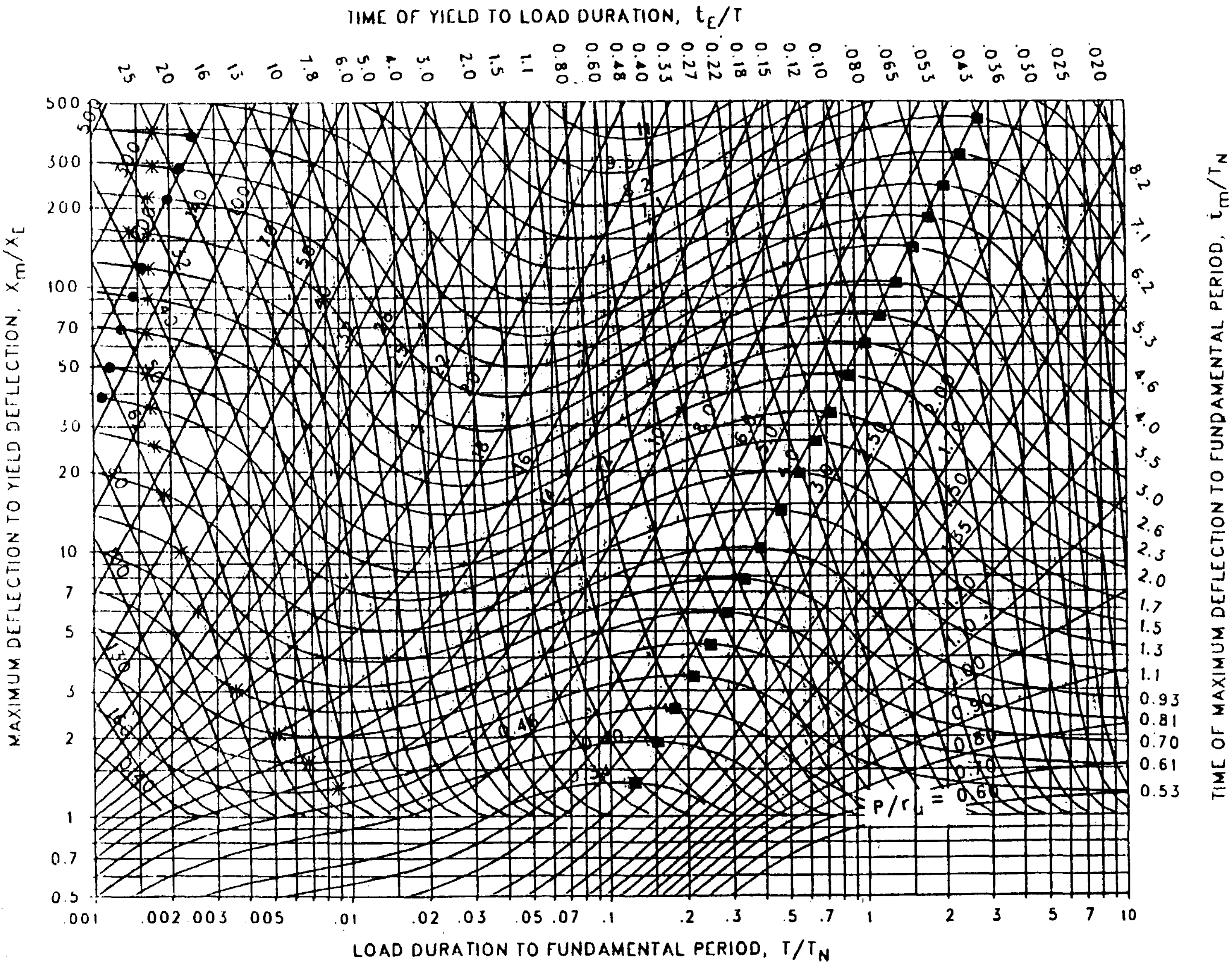


Figure 3-210 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.056, C_2 = 300.)

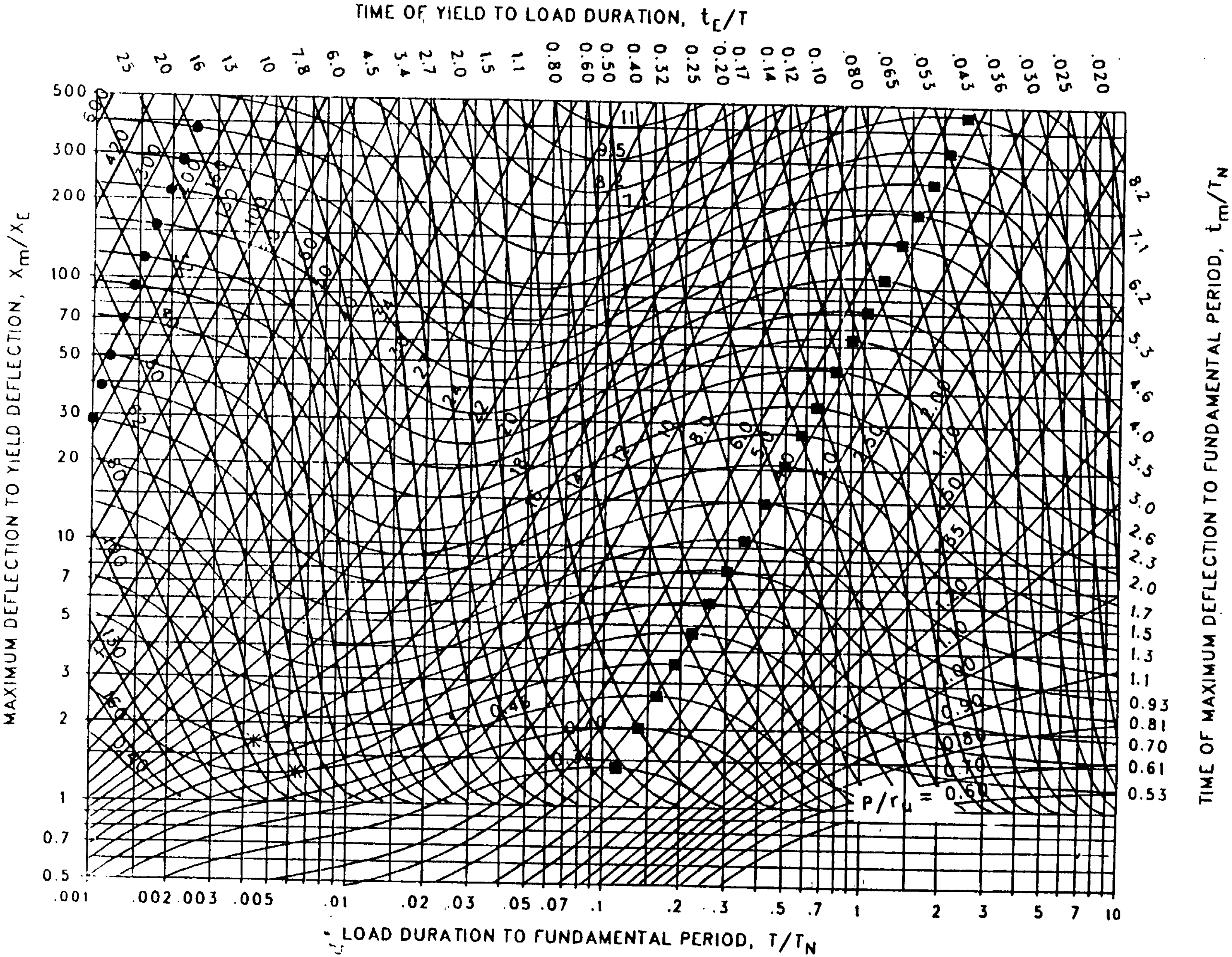


Figure 3-211 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.046, C_2 = 300.)

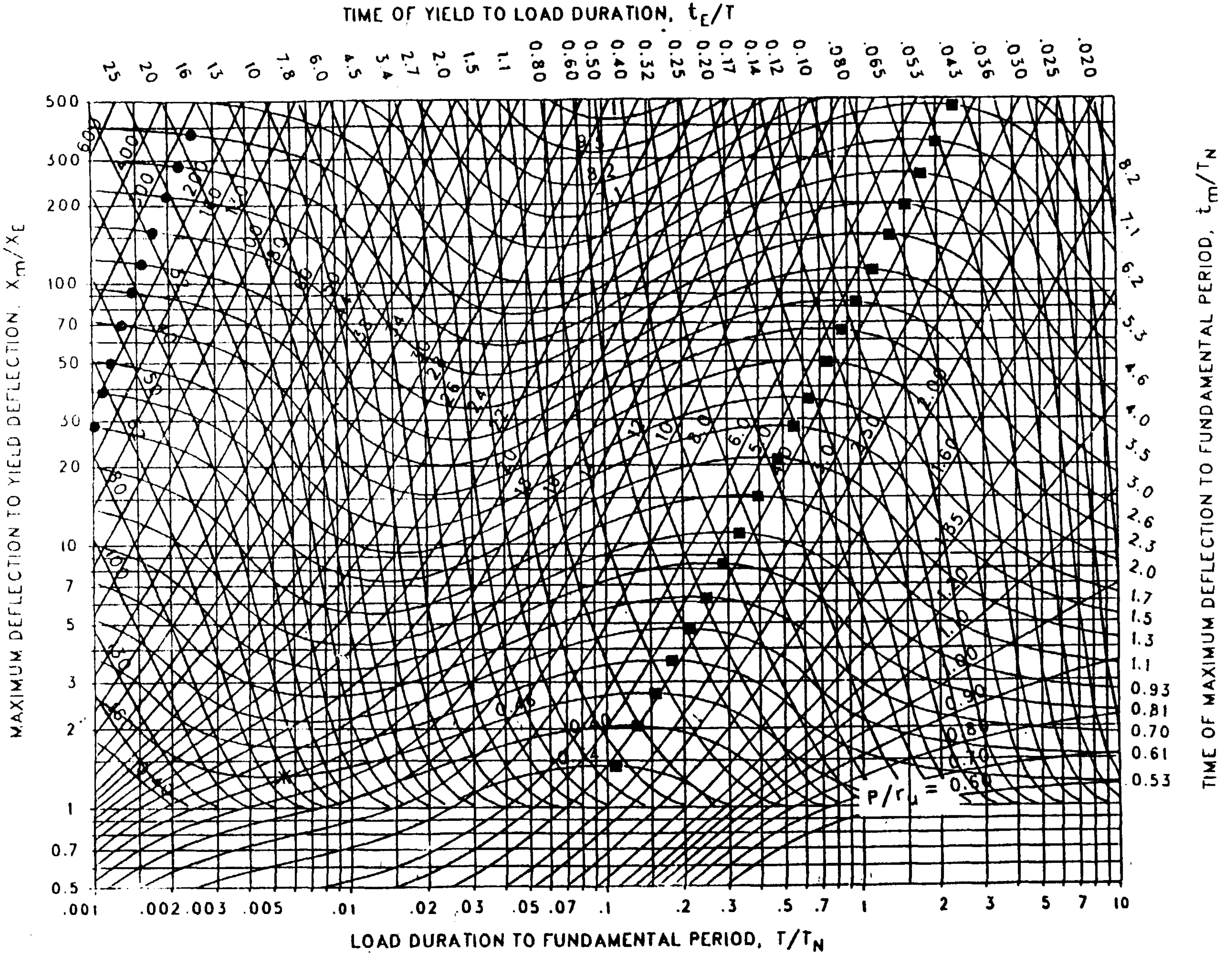


Figure 3-212 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.042, C_2 = 300.)

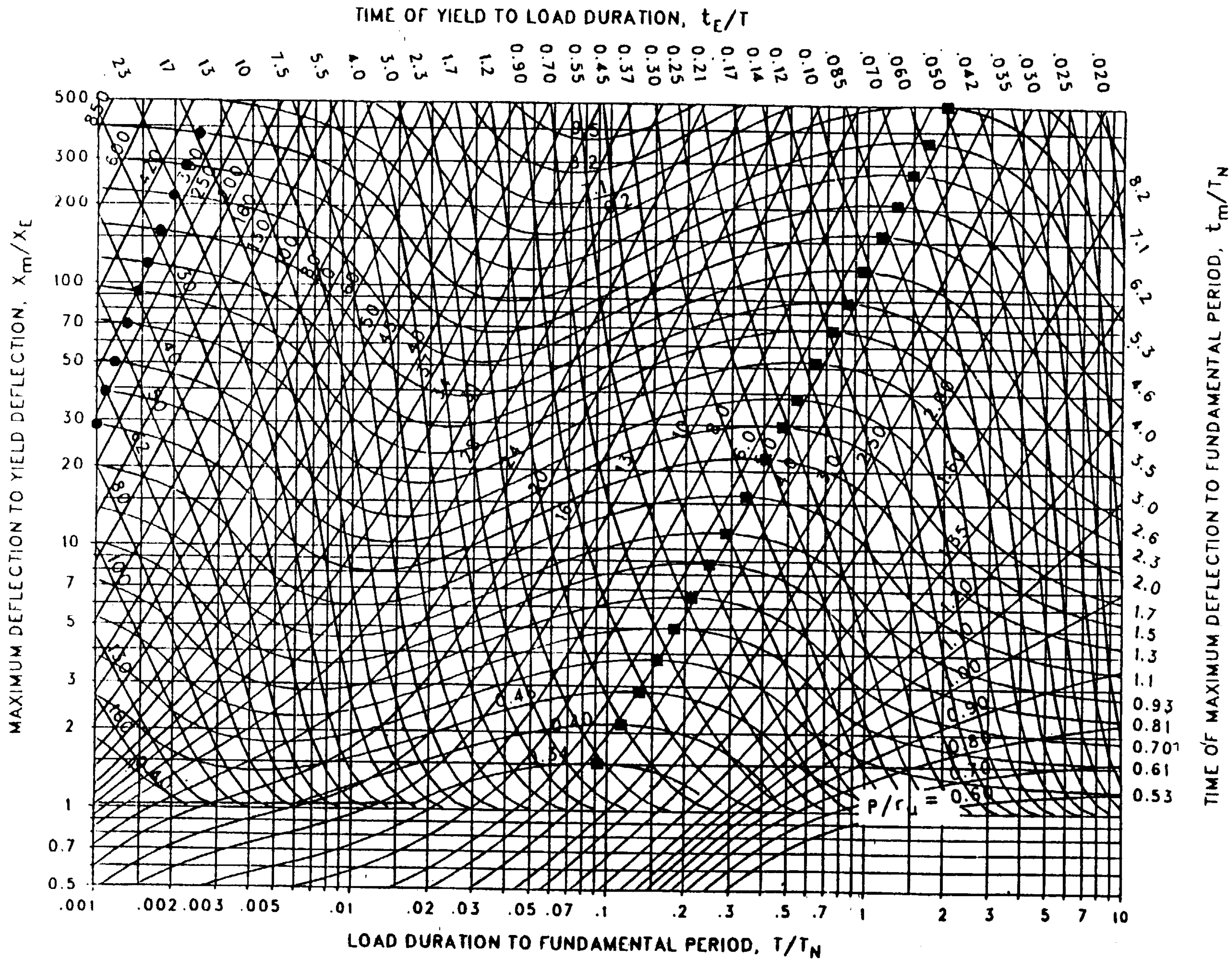


Figure 3-213 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.032, C_2 = 300.)

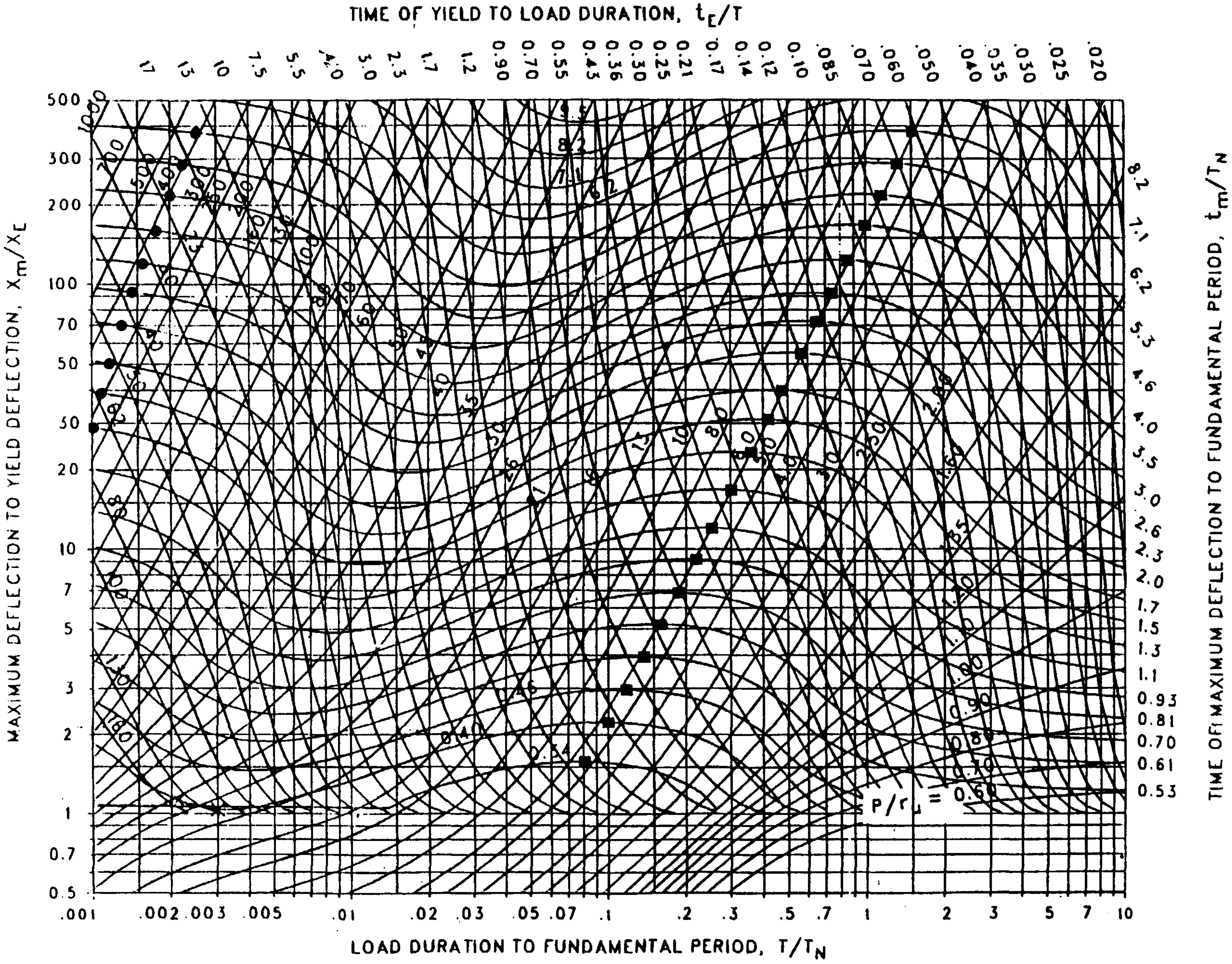


Figure 3-214 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.026, C_2 = 300.)

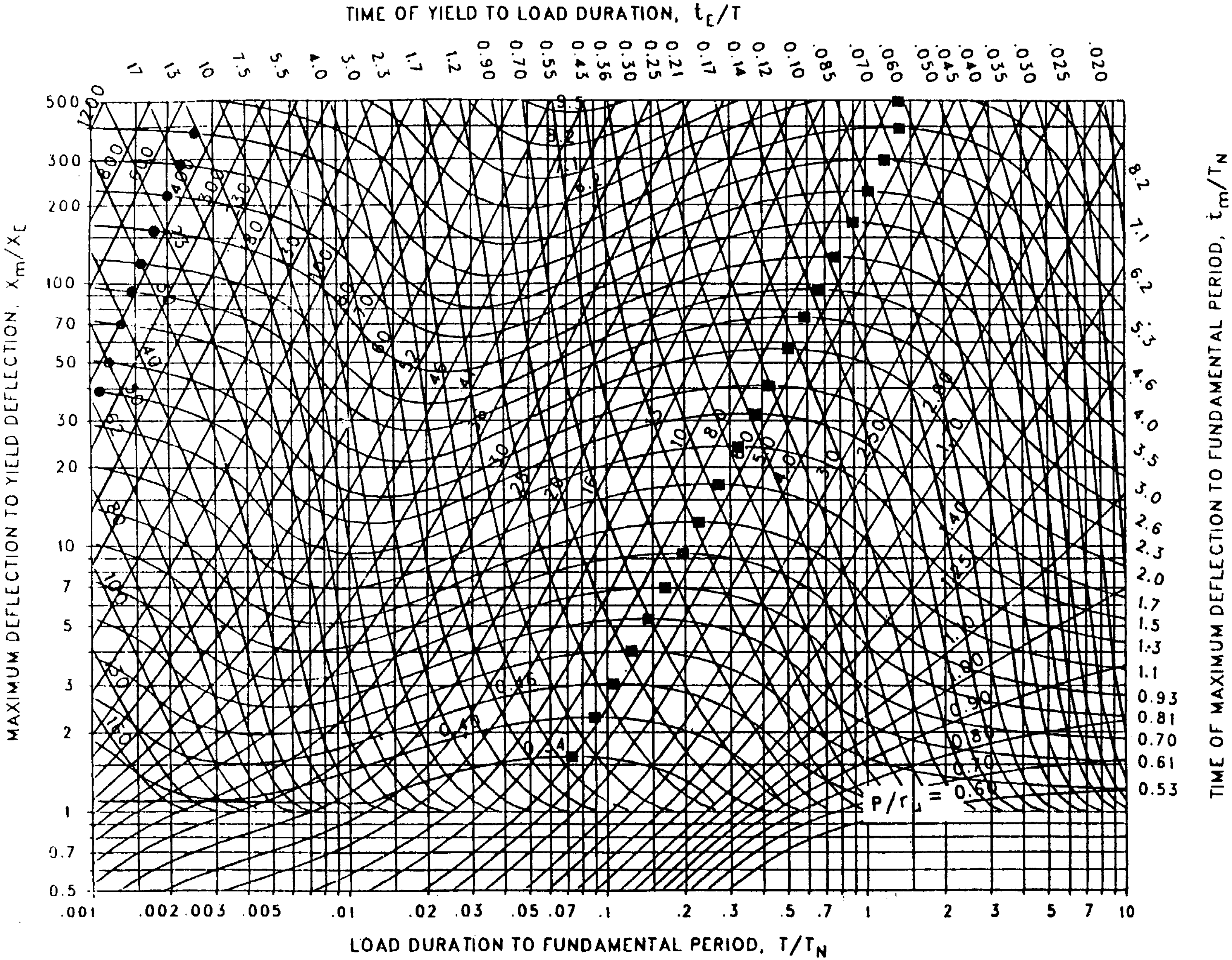


Figure 3-215 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.022, C_2 = 300.)

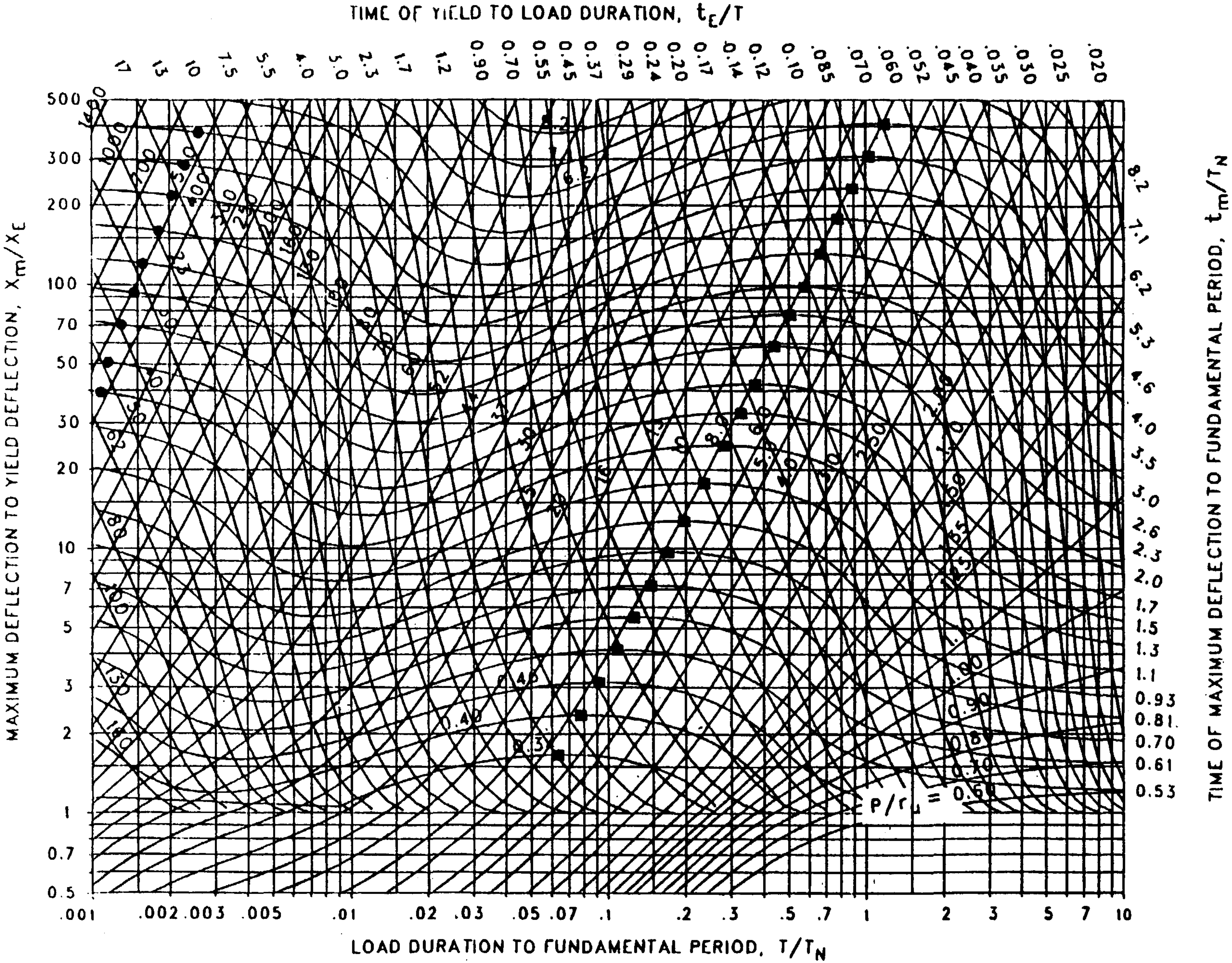


Figure 3-216 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.018, C_2 = 300.)

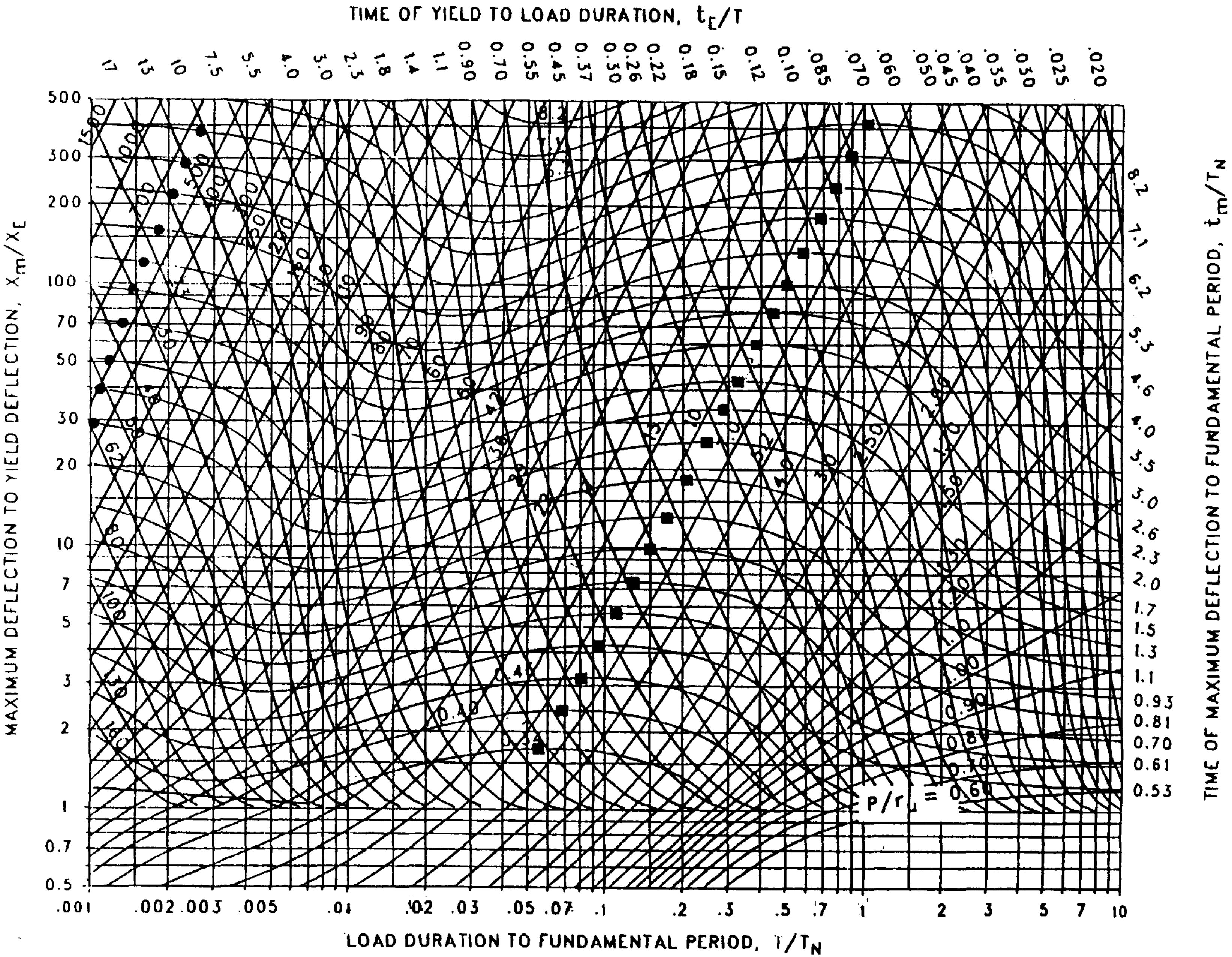


Figure 3-217 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.015, C_2 = 300.)

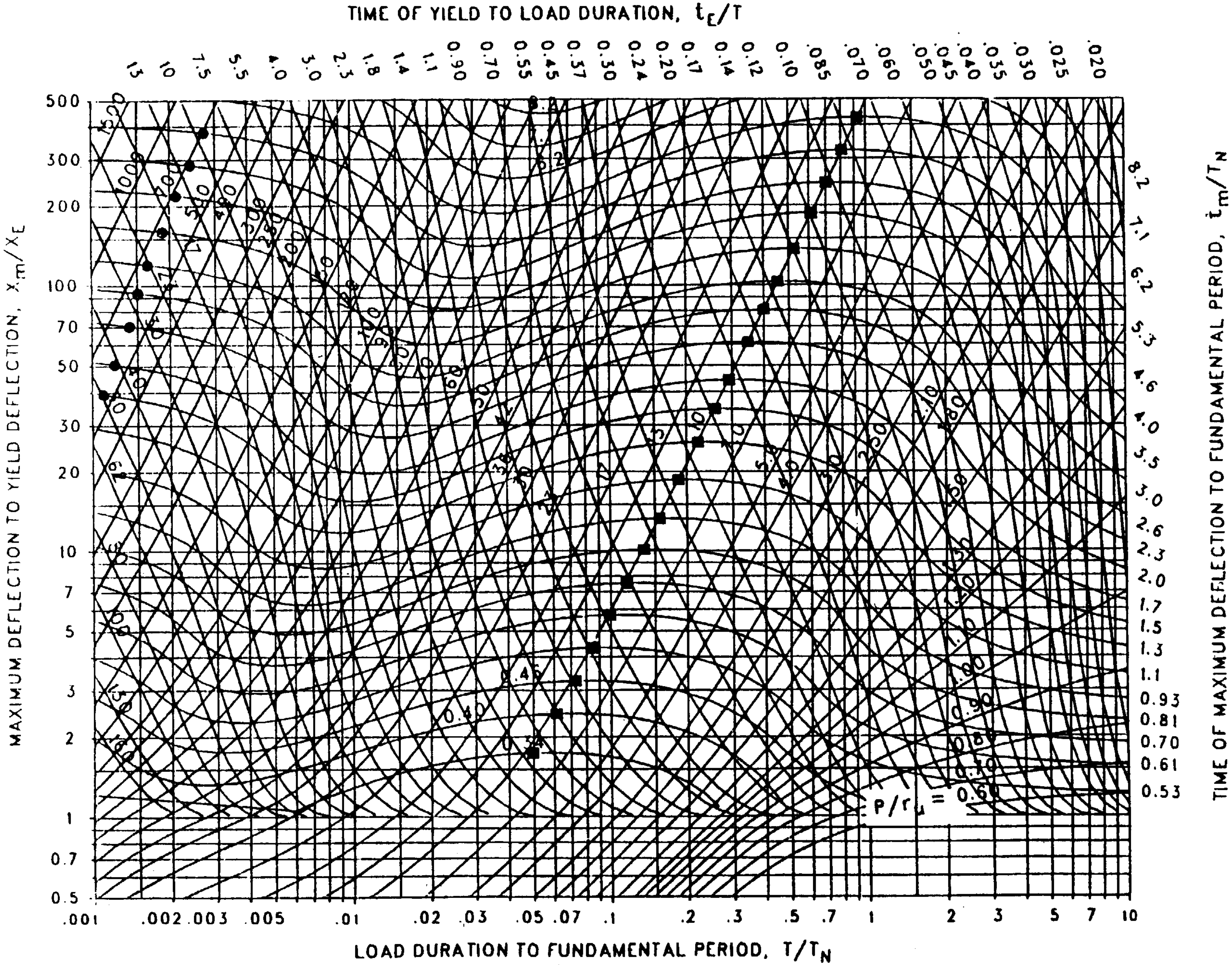


Figure 3-218 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.013, C_2 = 300.)

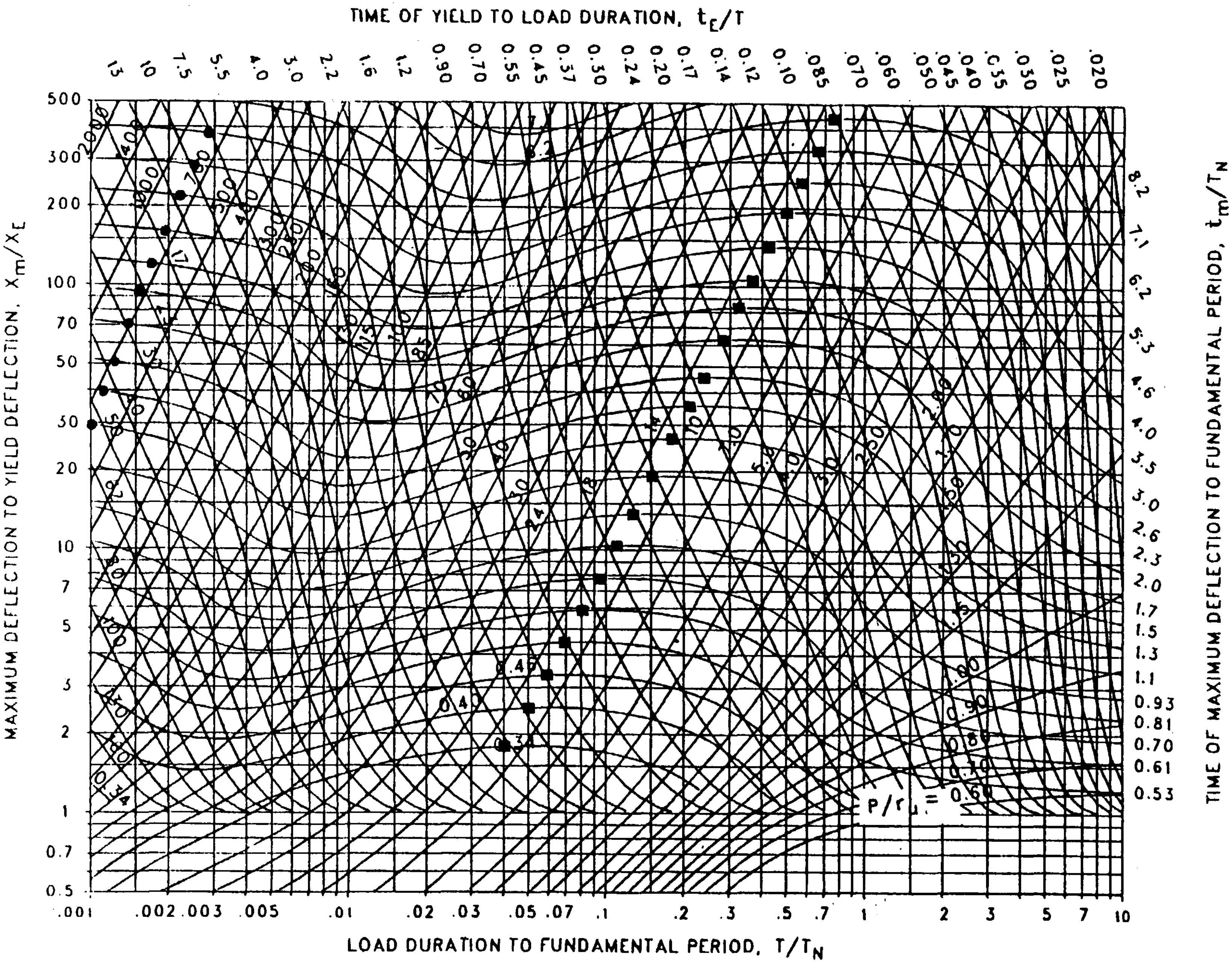


Figure 3-219 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.010, C_2 = 300.)

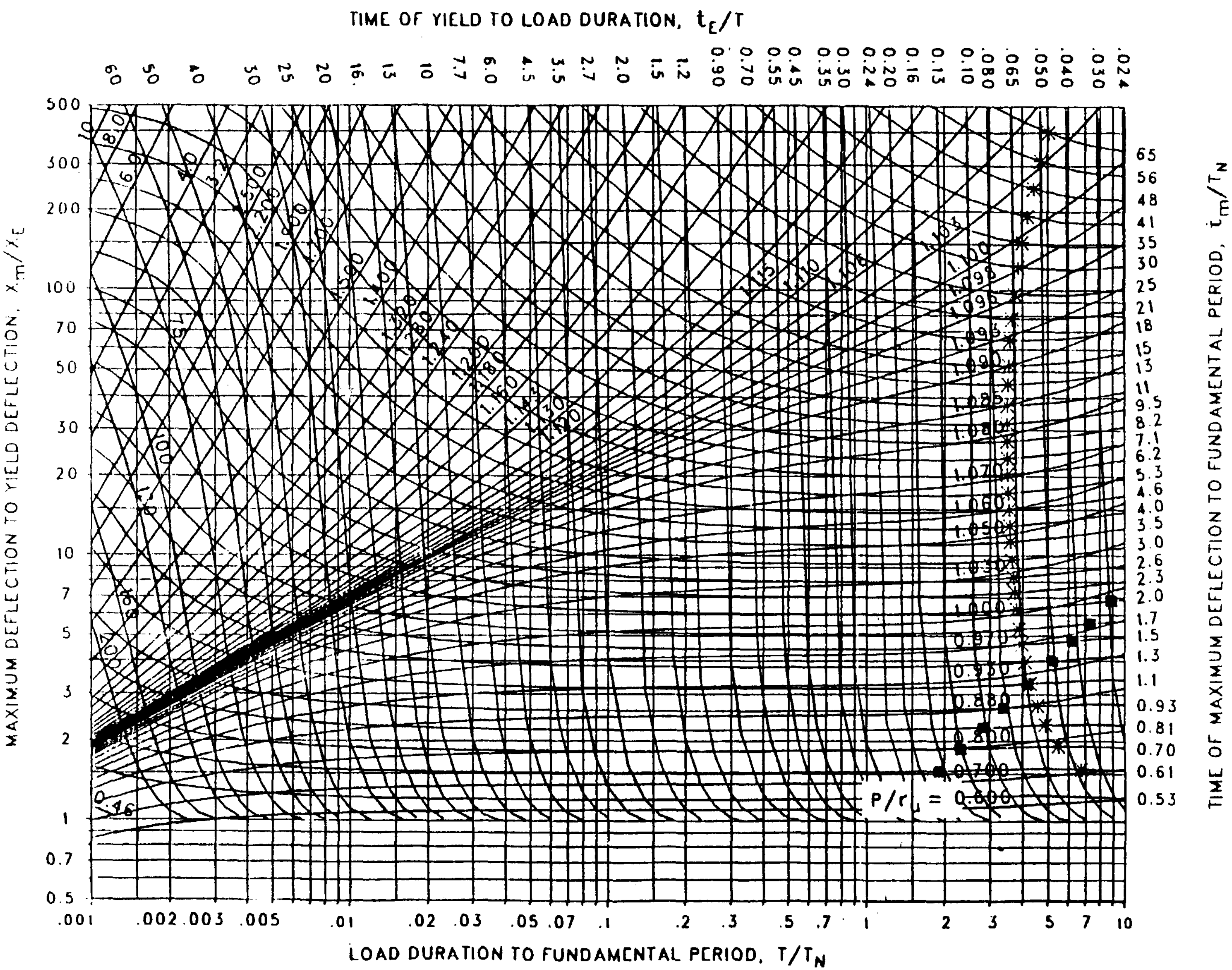


Figure 3-220 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.909, C_2 = 1000.)

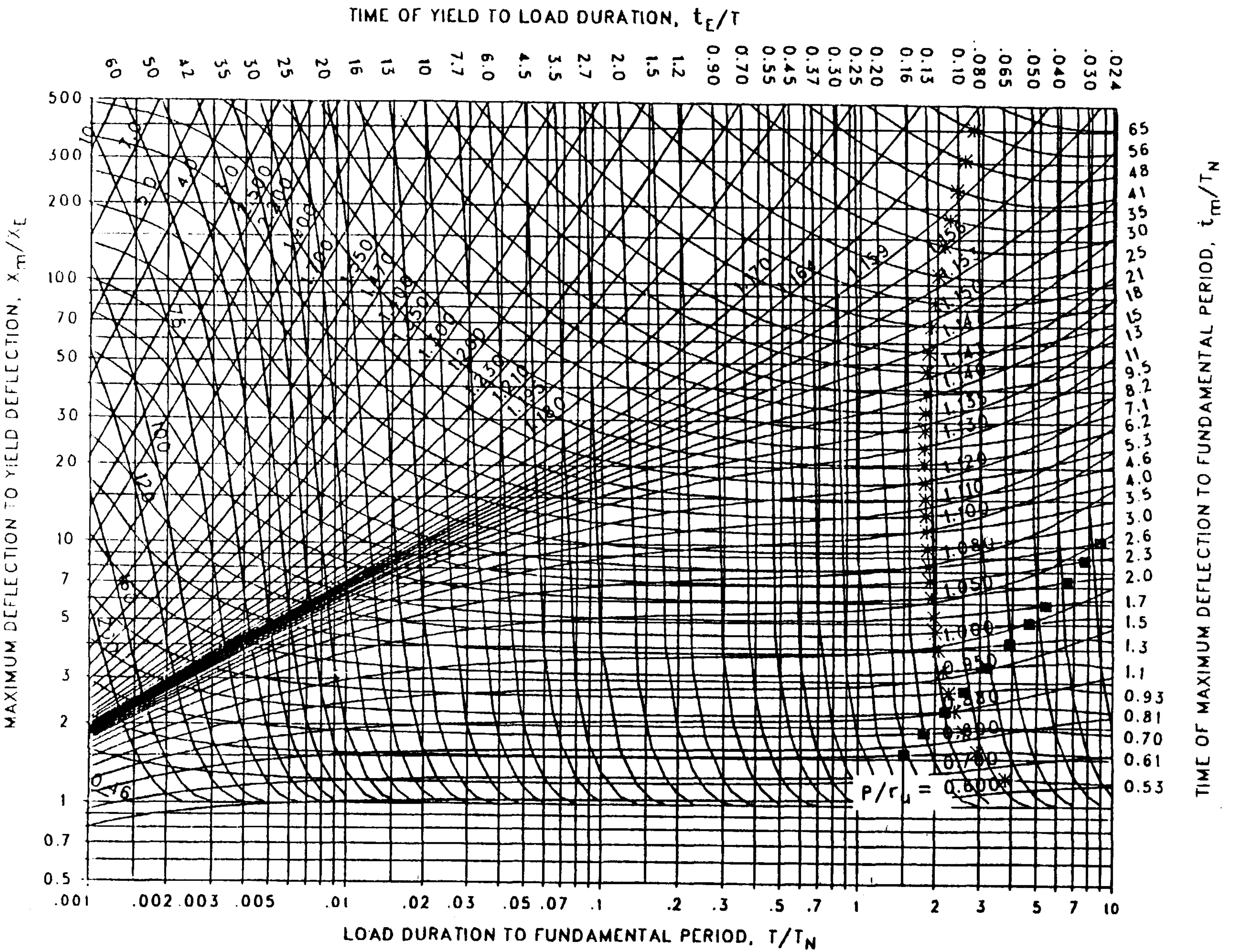


Figure 3-221 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.866, C_2 = 1000.)

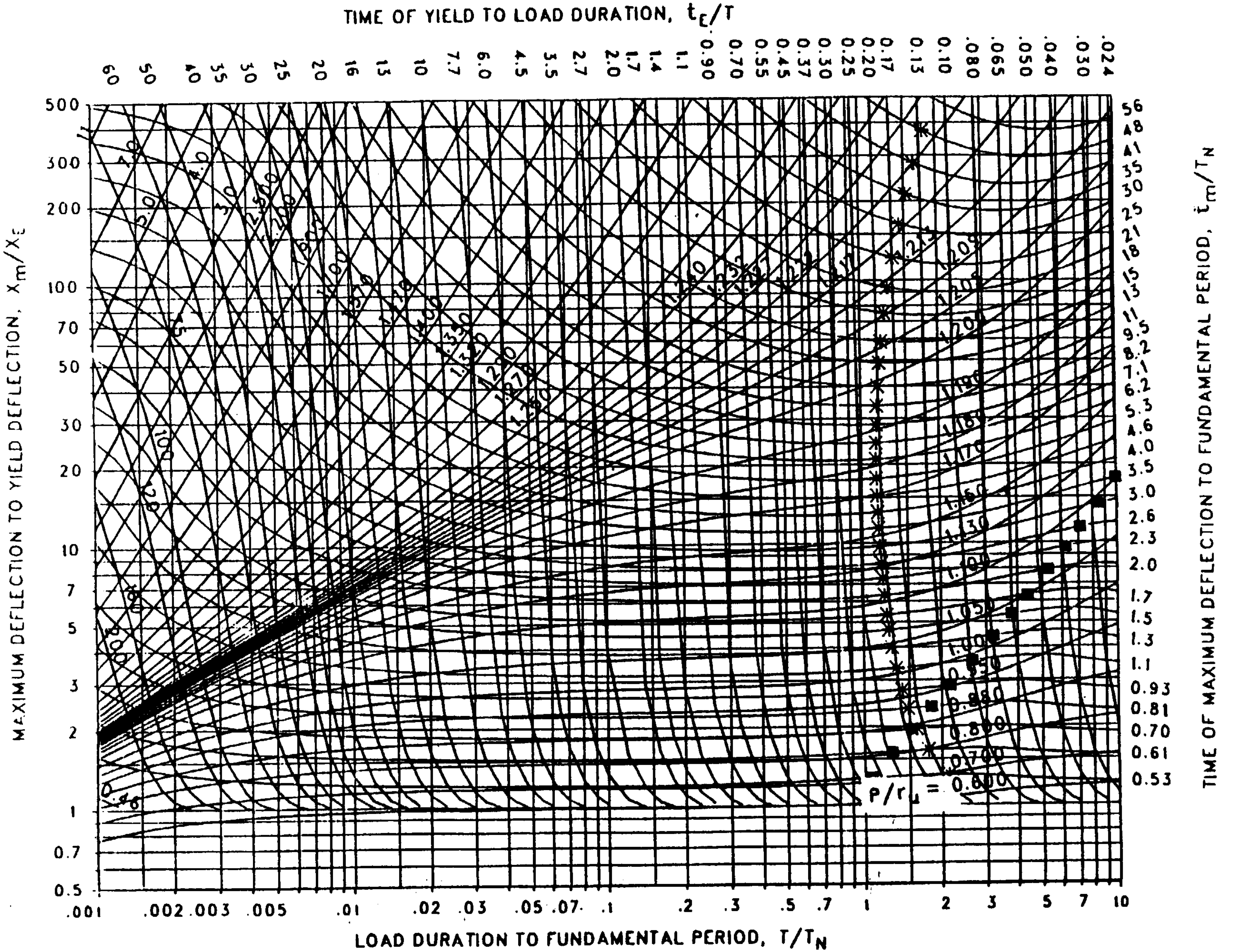


Figure 3-222 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.825, C_2 = 1000.)

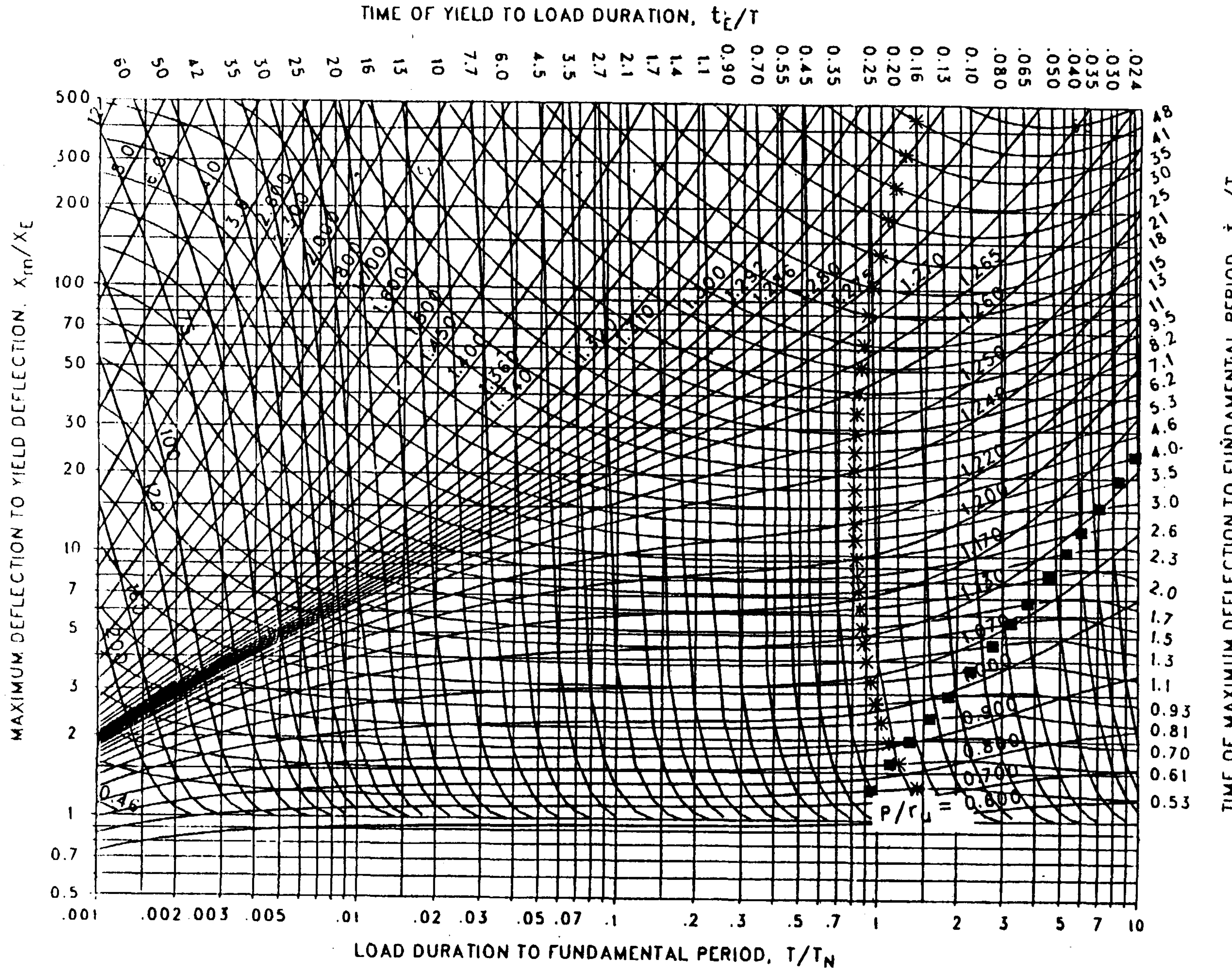


Figure 3-223 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.787, C_2 = 1000.)

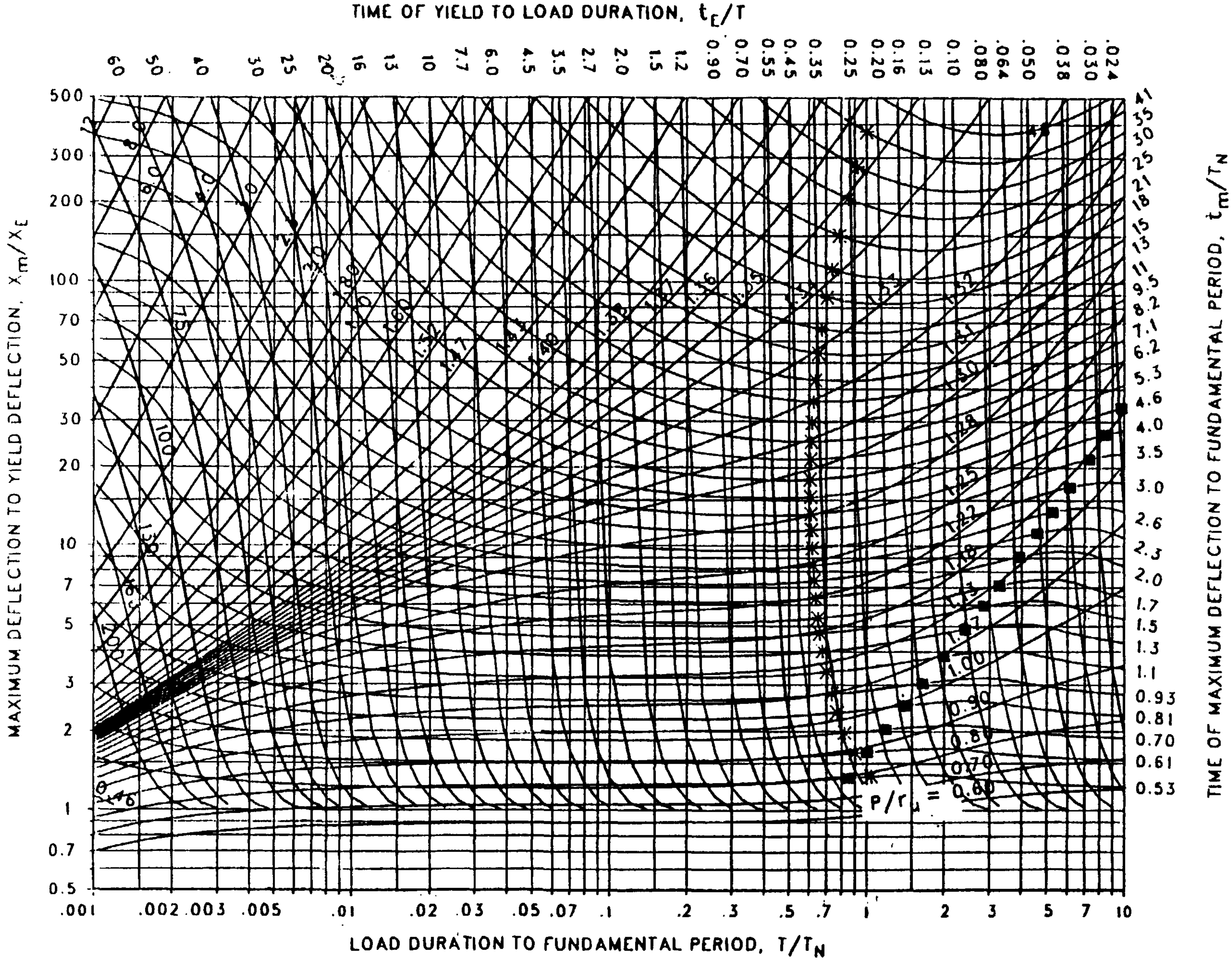


Figure 3-224 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.750, C_2 = 1000.)

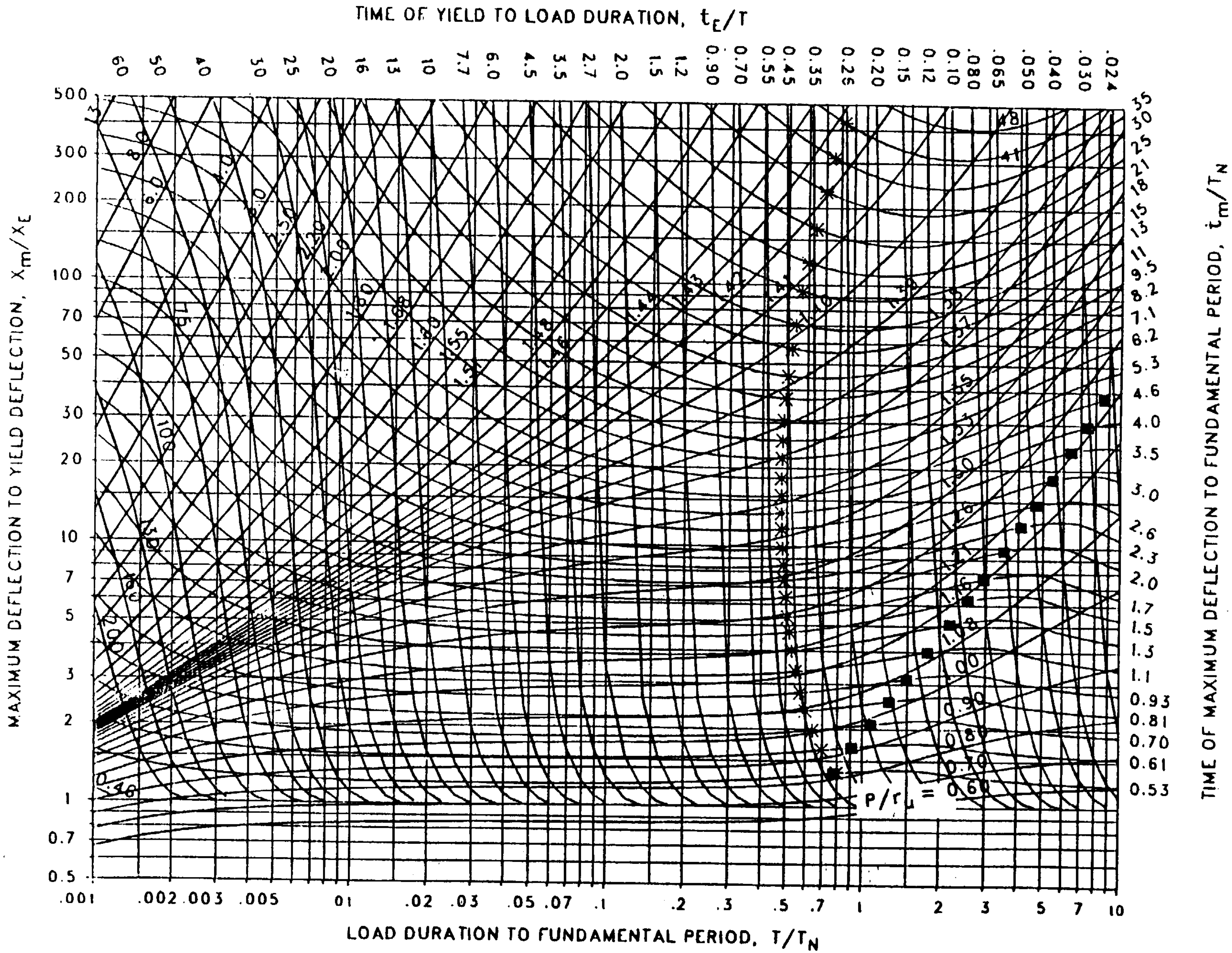


Figure 3-225 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.715, C_2 = 1000.)

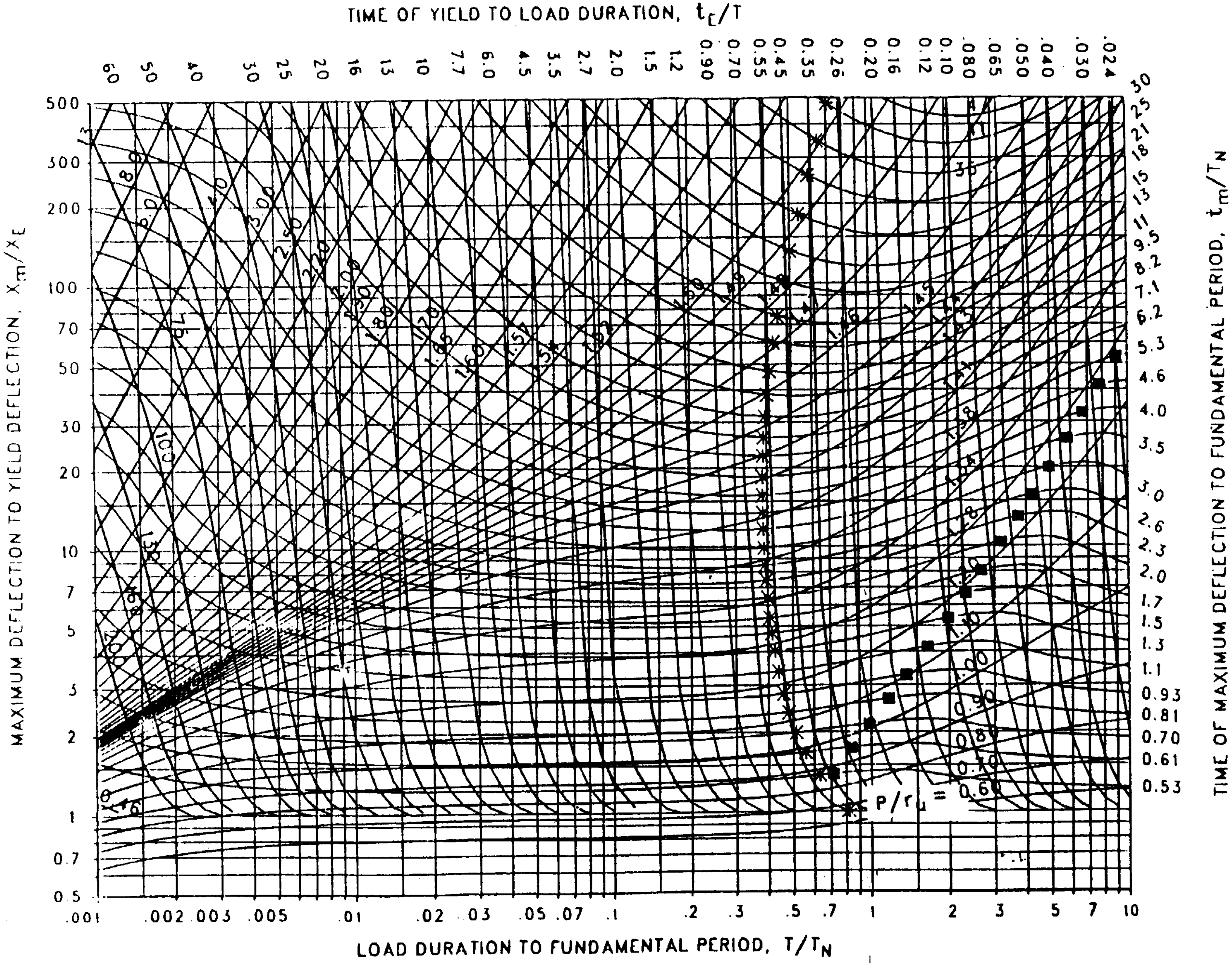


Figure 3-226 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.681, C_2 = 1000.)

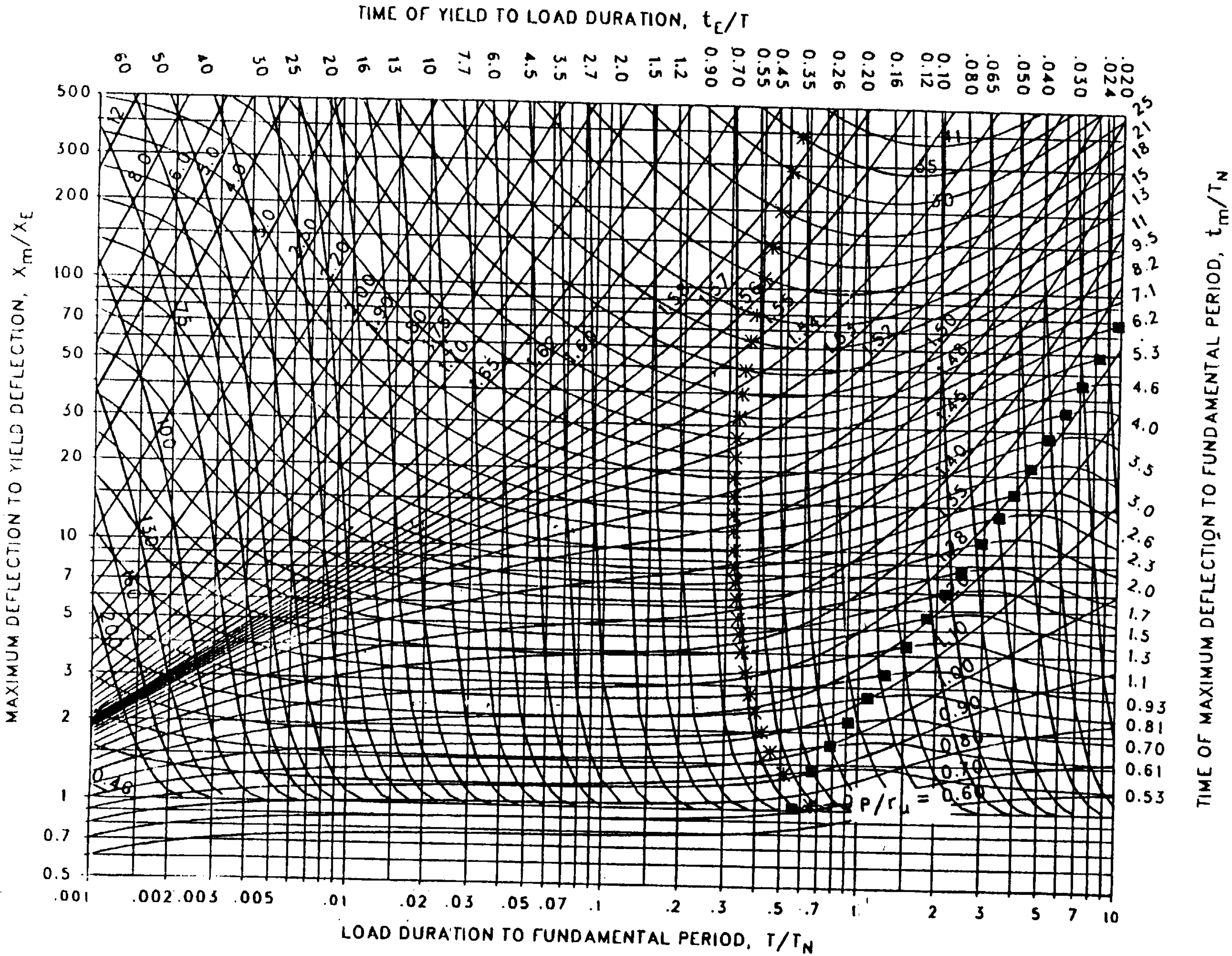


Figure 3-227 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.648, C_2 = 1000.)

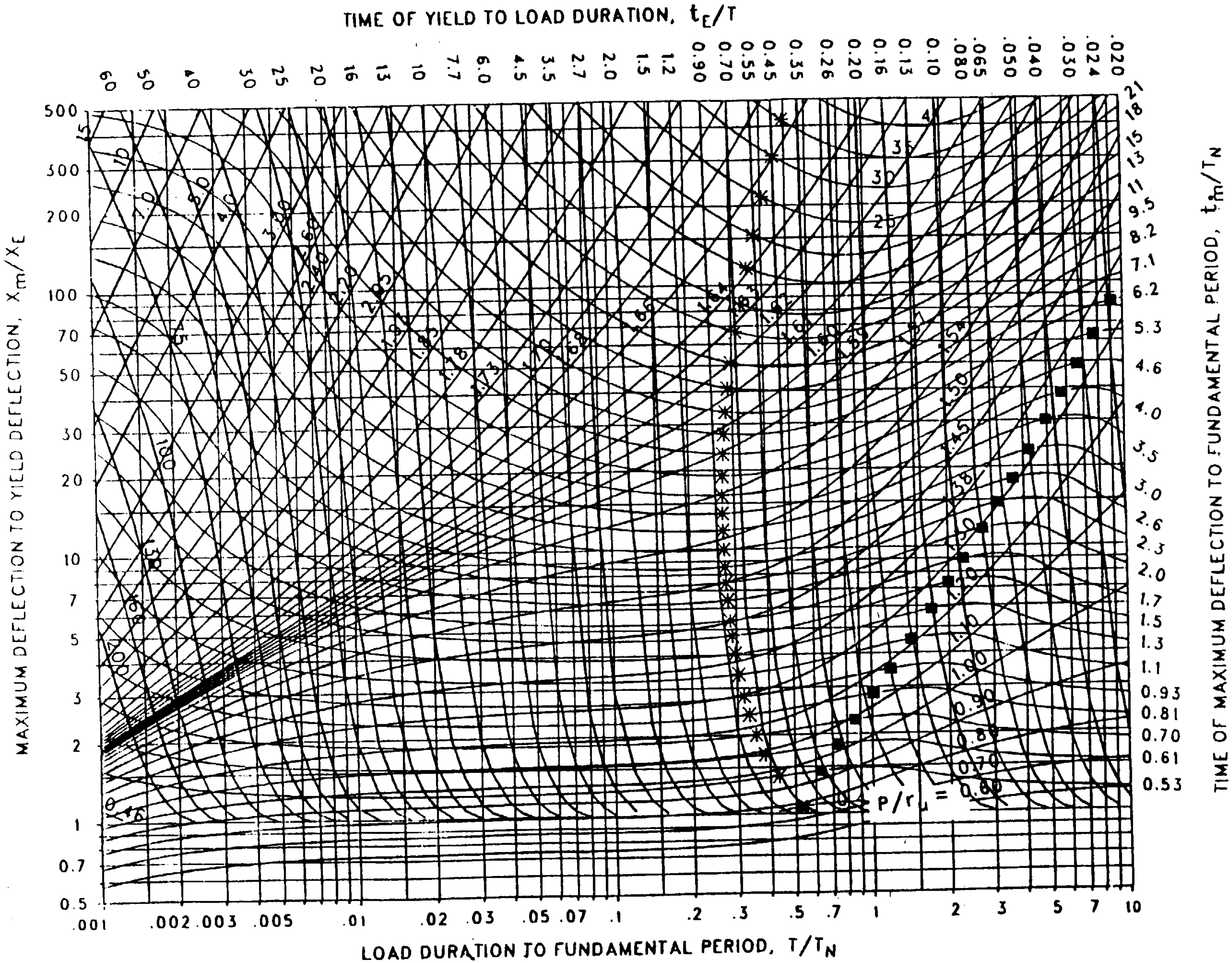


Figure 3-228 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.619, C_2 = 1000.)

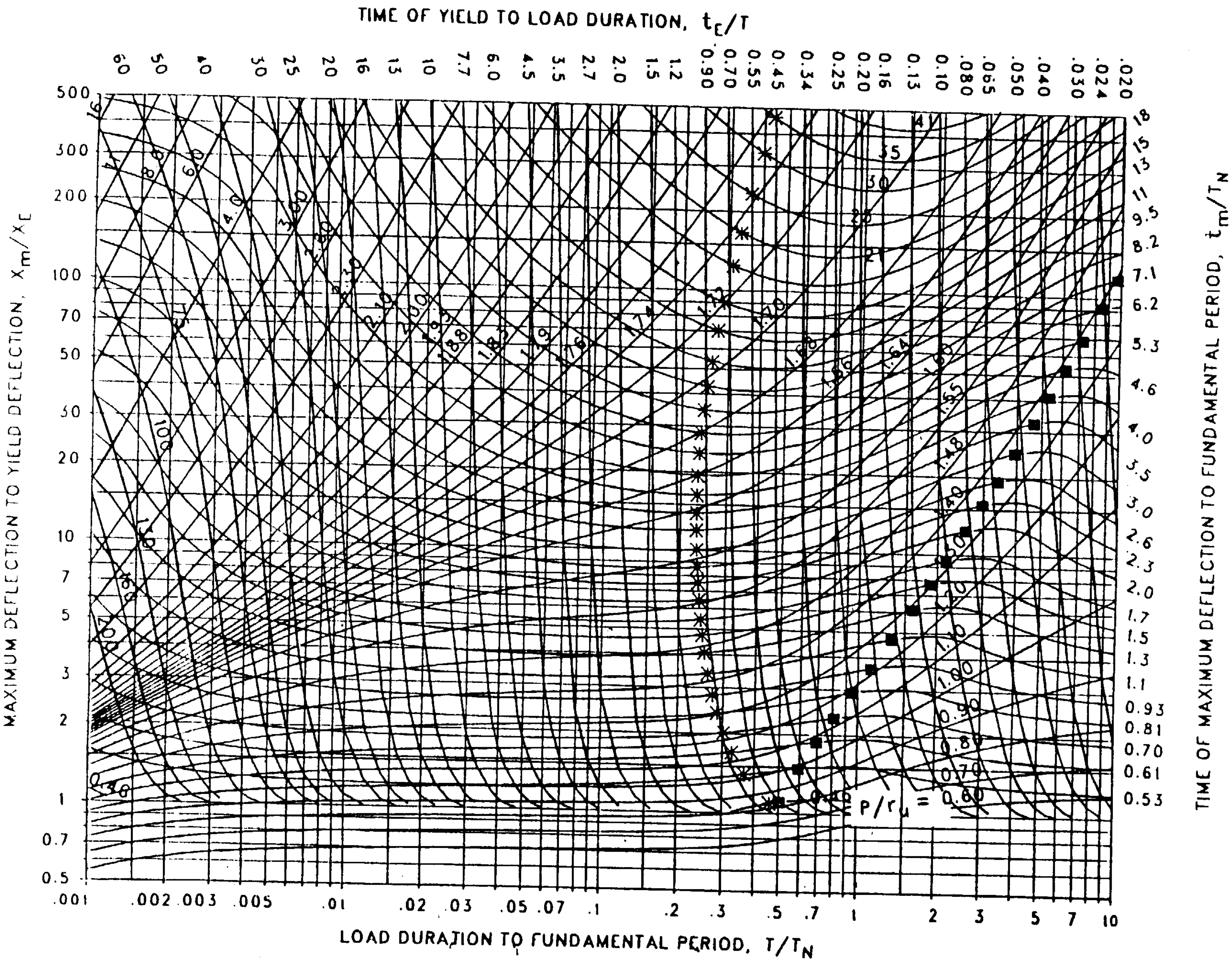


Figure 3-229 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.590, C_2 = 1000.)

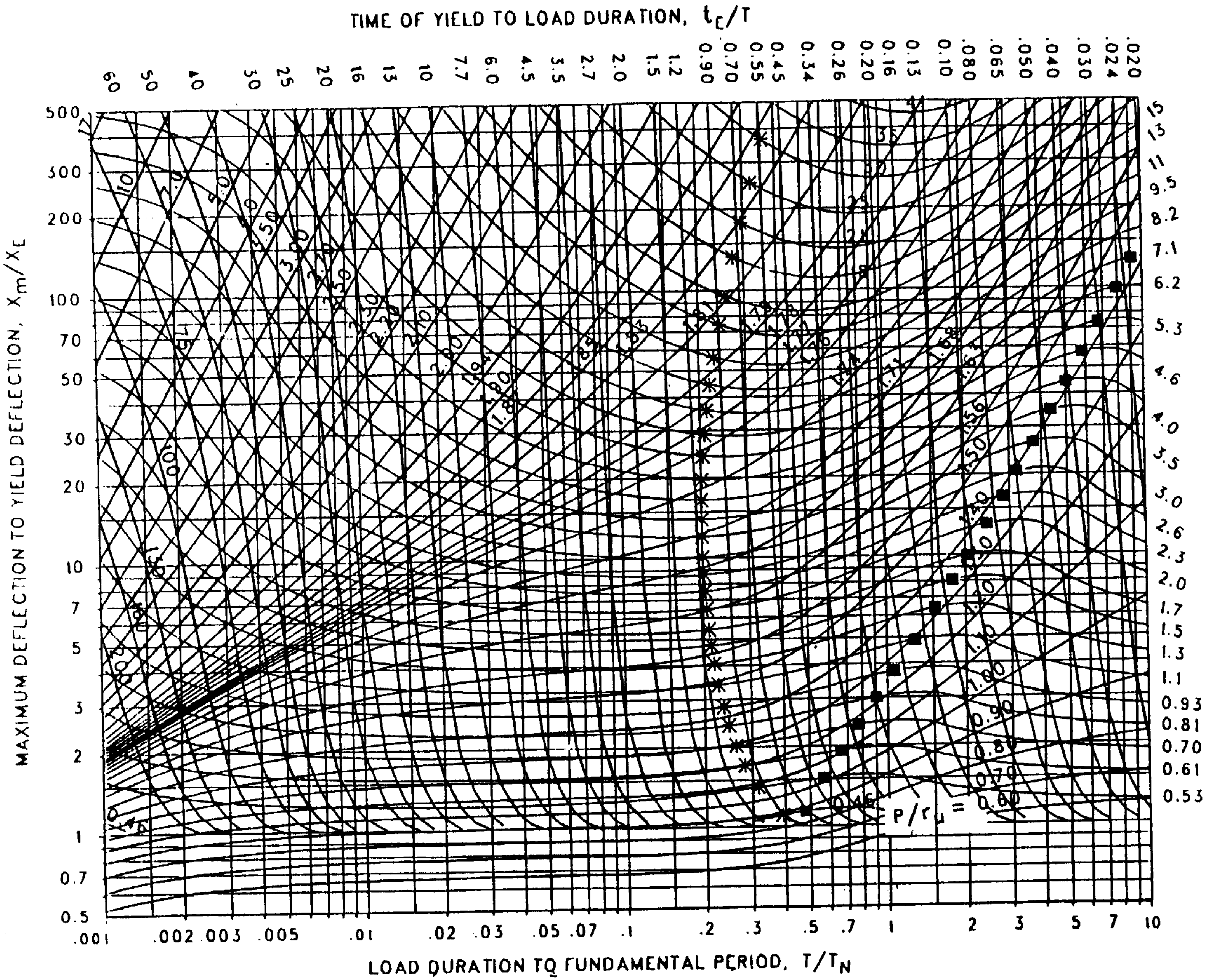


Figure 3-230 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.562, C_2 = 1000.)

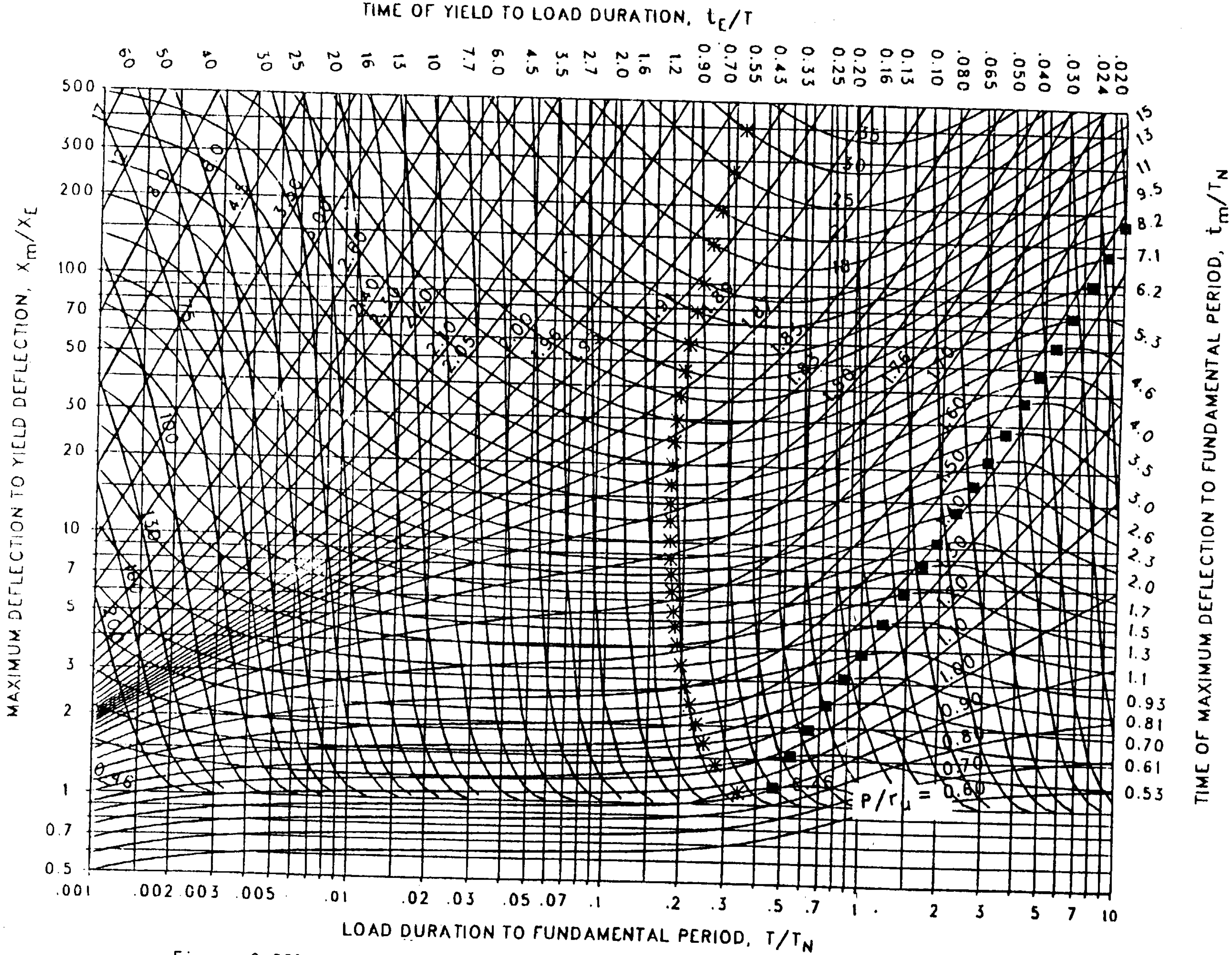


Figure 3-231 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.536, C_2 = 1000.)

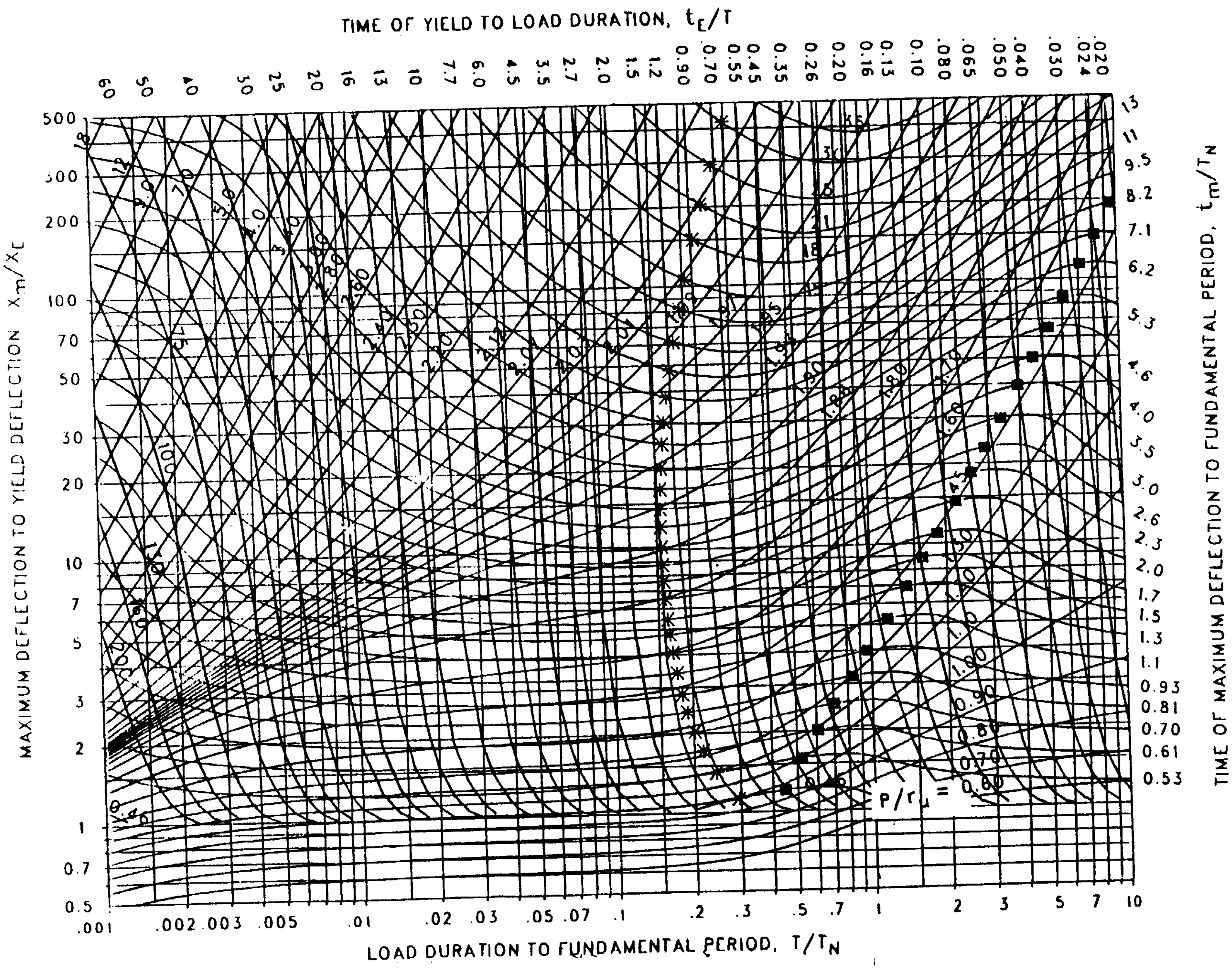


Figure 3-232 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.511, C_2 = 1000.)

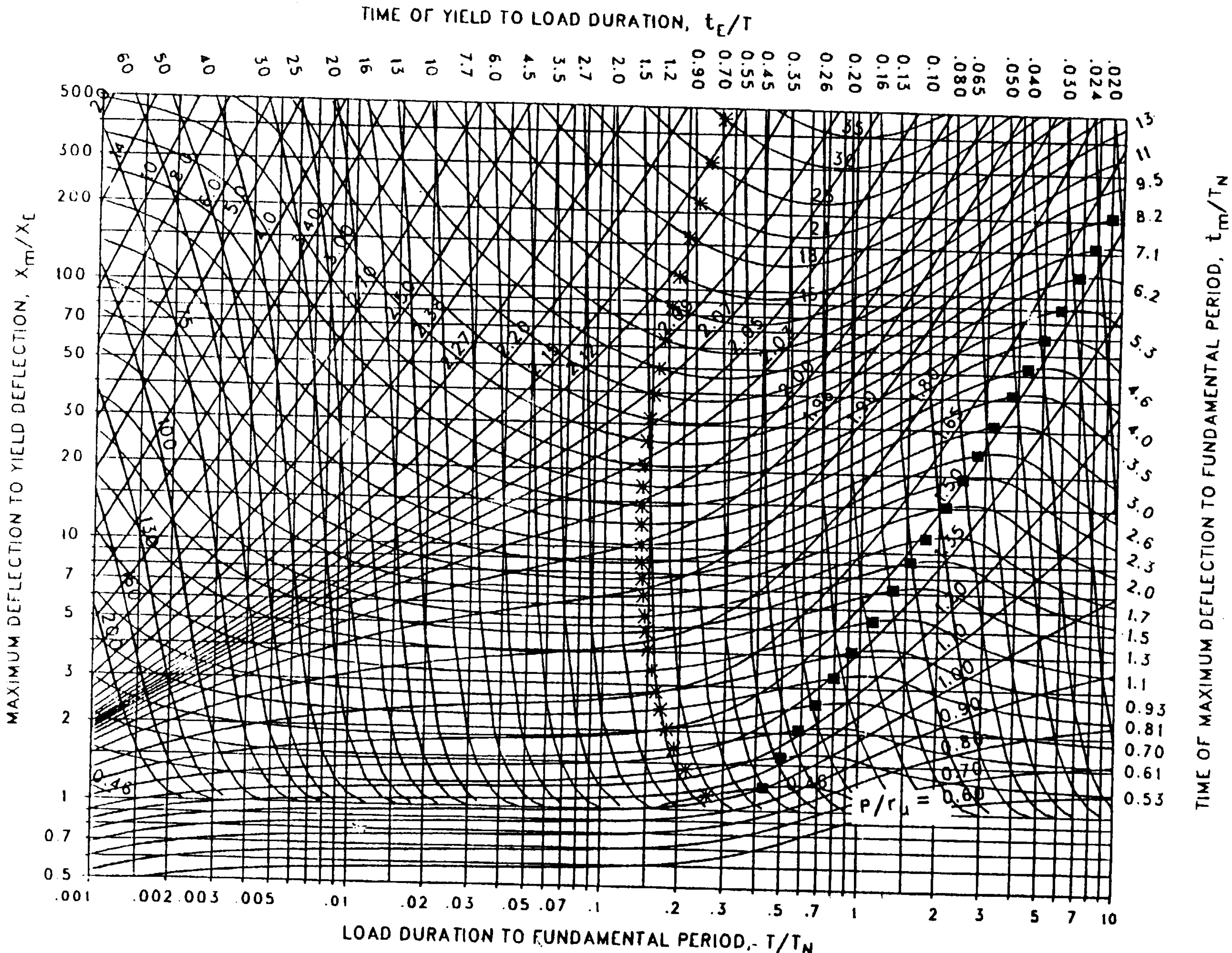


Figure 3-233 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.487, C_2 = 1000.)

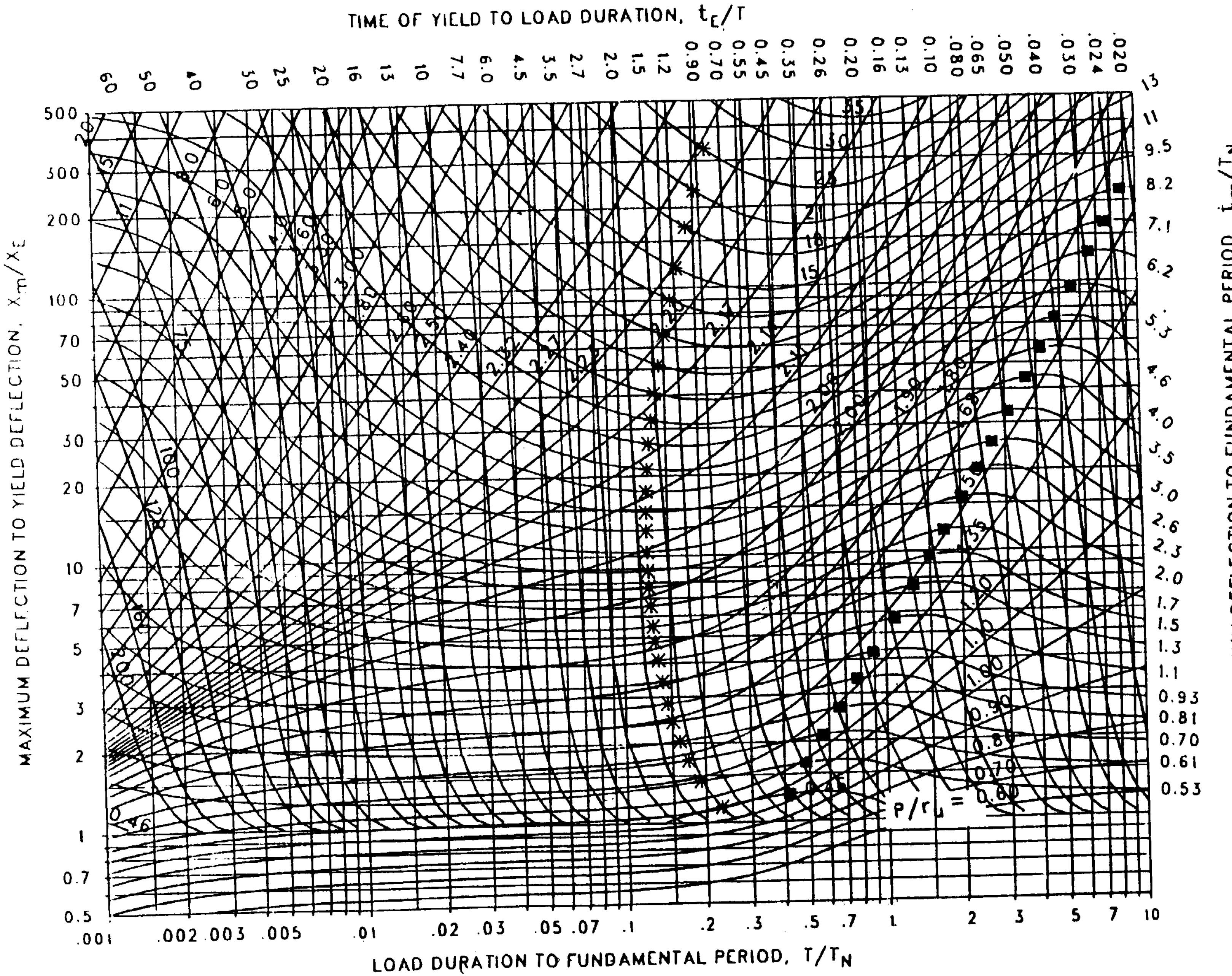


Figure 3-234 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.464, C_2 = 1000.)

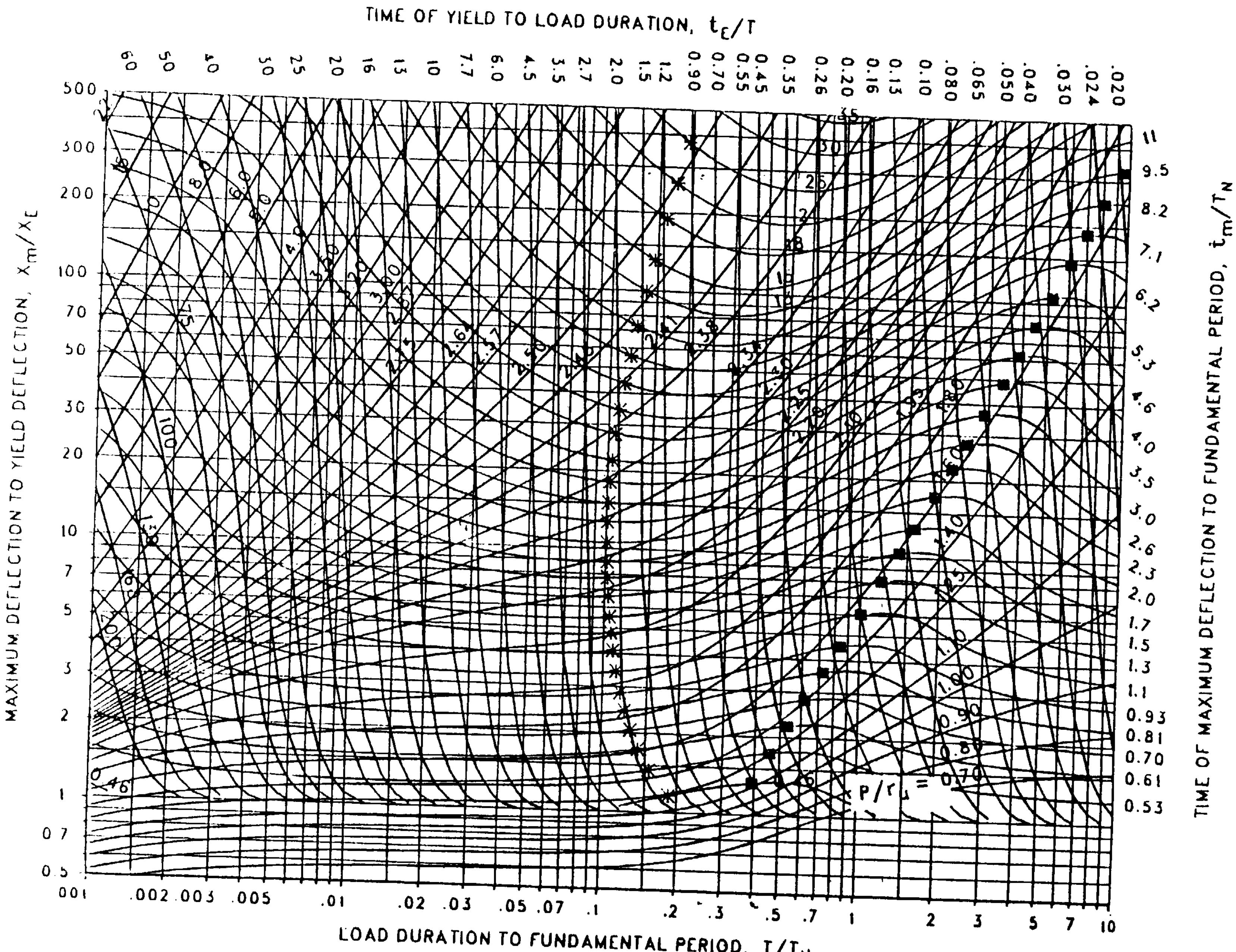


Figure 3-235 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.422, C_2 = 1000.)

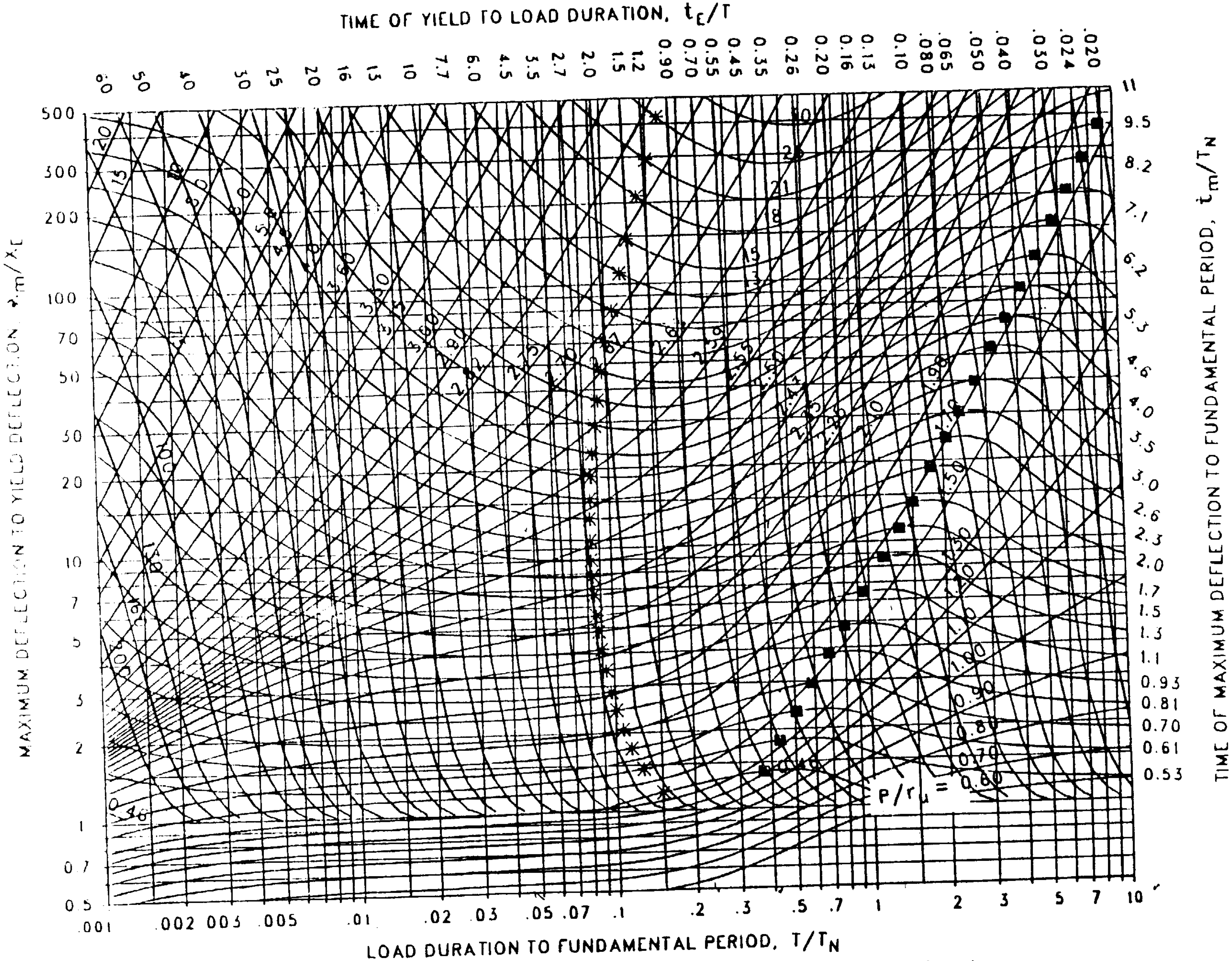


Figure 3-236 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.383, C_2 = 1000.)

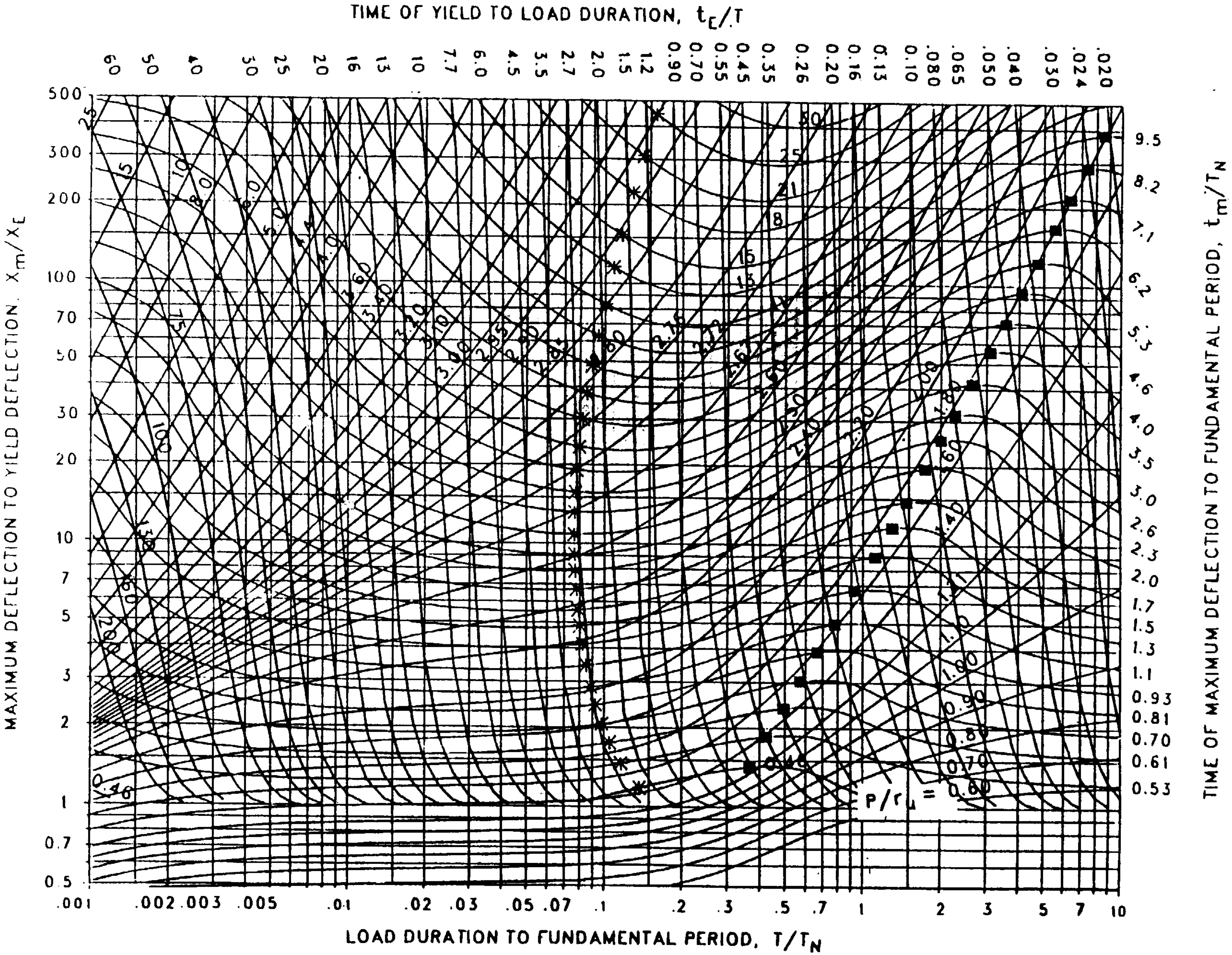


Figure 3-237 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.365, C_2 = 1000.)

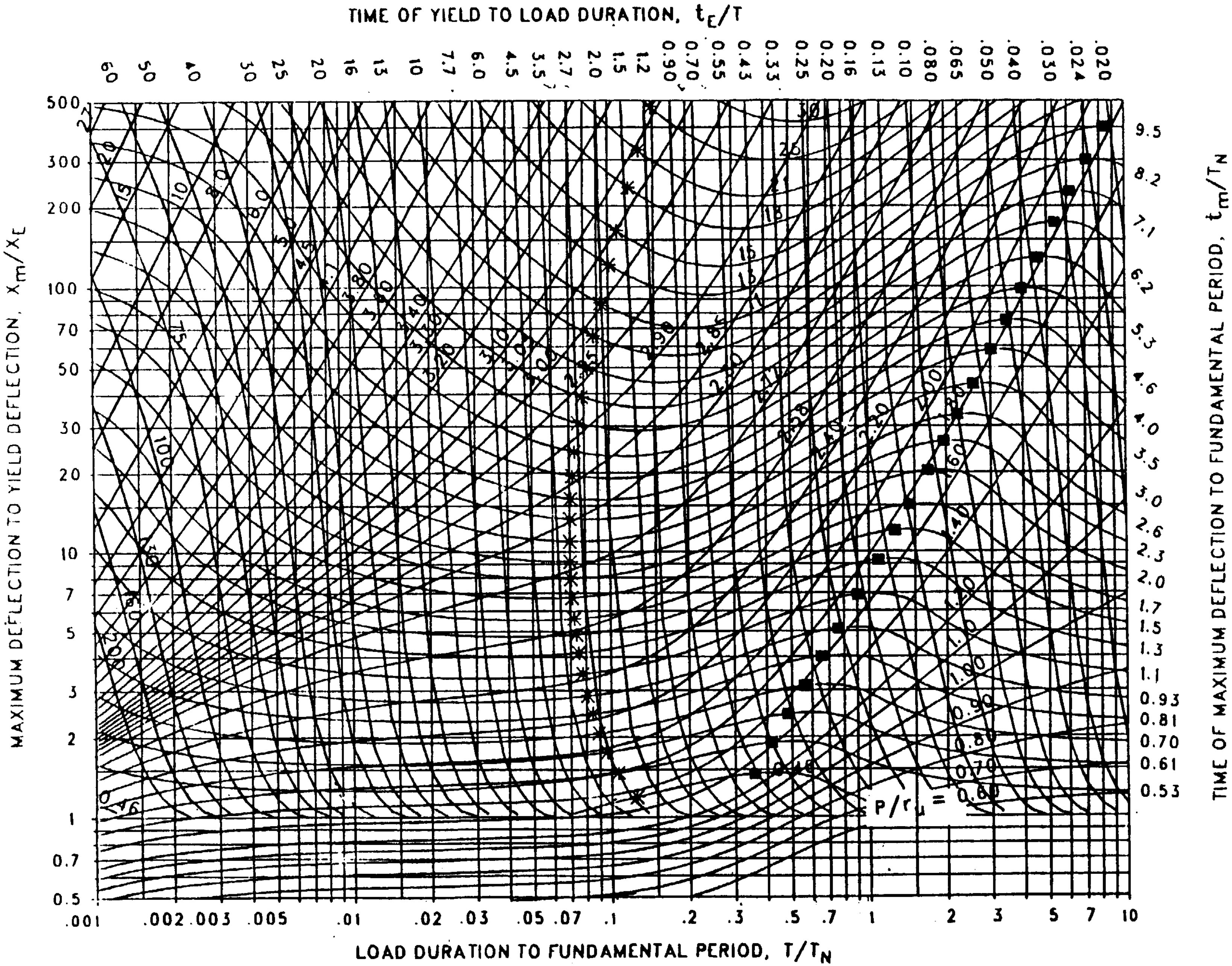


Figure 3-238 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.348, C_2 = 1000.)

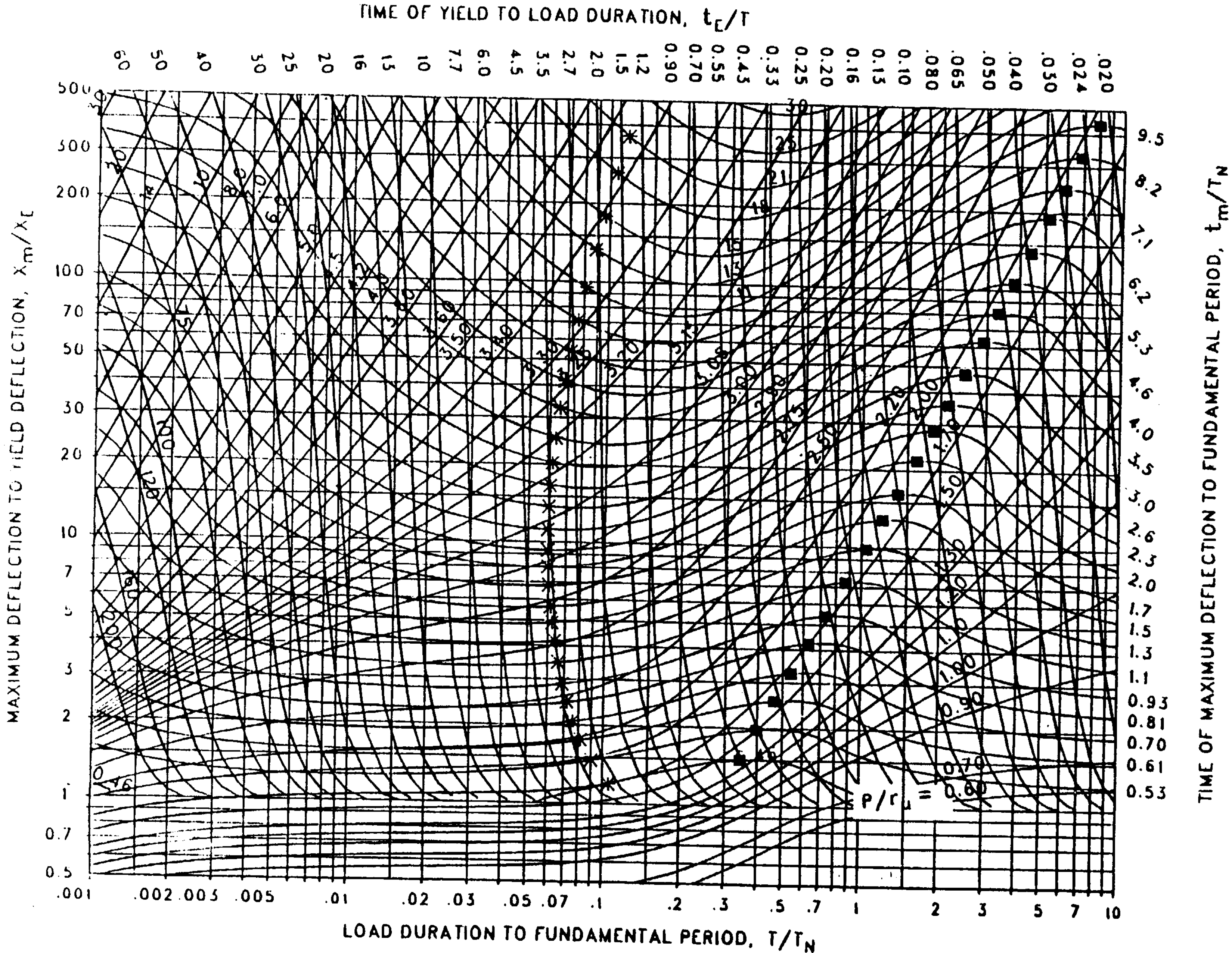


Figure 3-239 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.316, C_2 = 1000.)

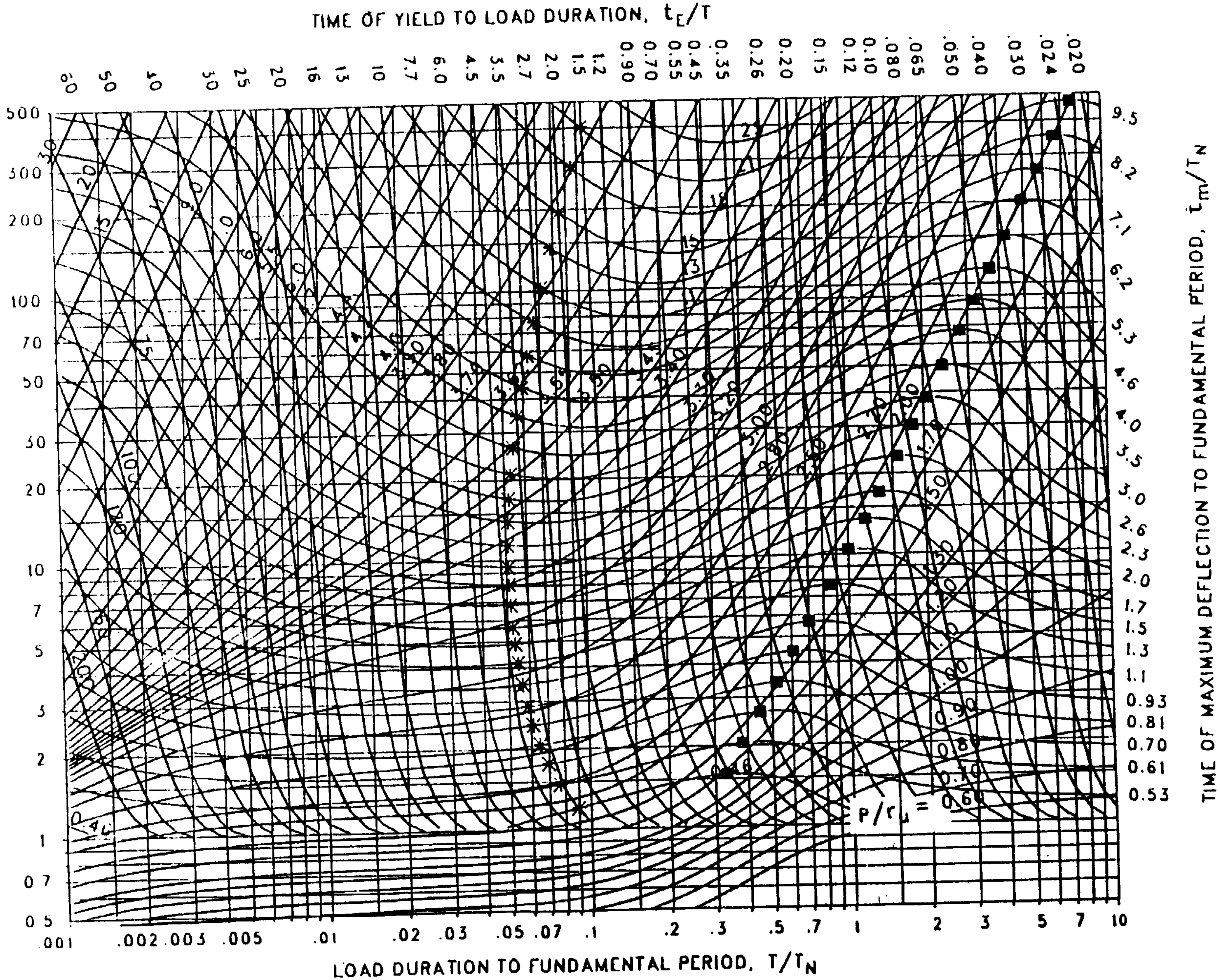


Figure 3-240 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.287, C_2 = 1000.)

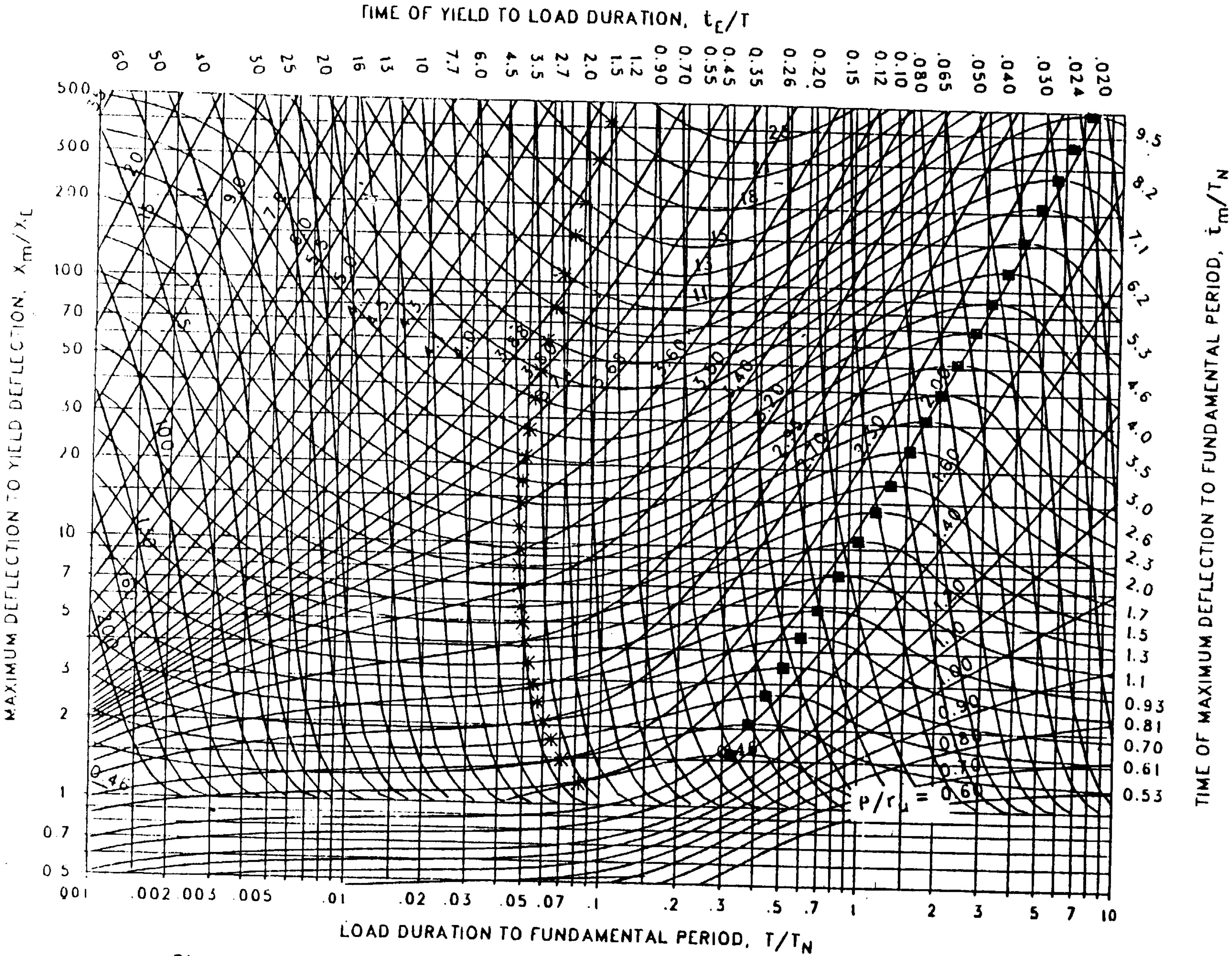


Figure 3-241 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.274, C_2 = 1000.)

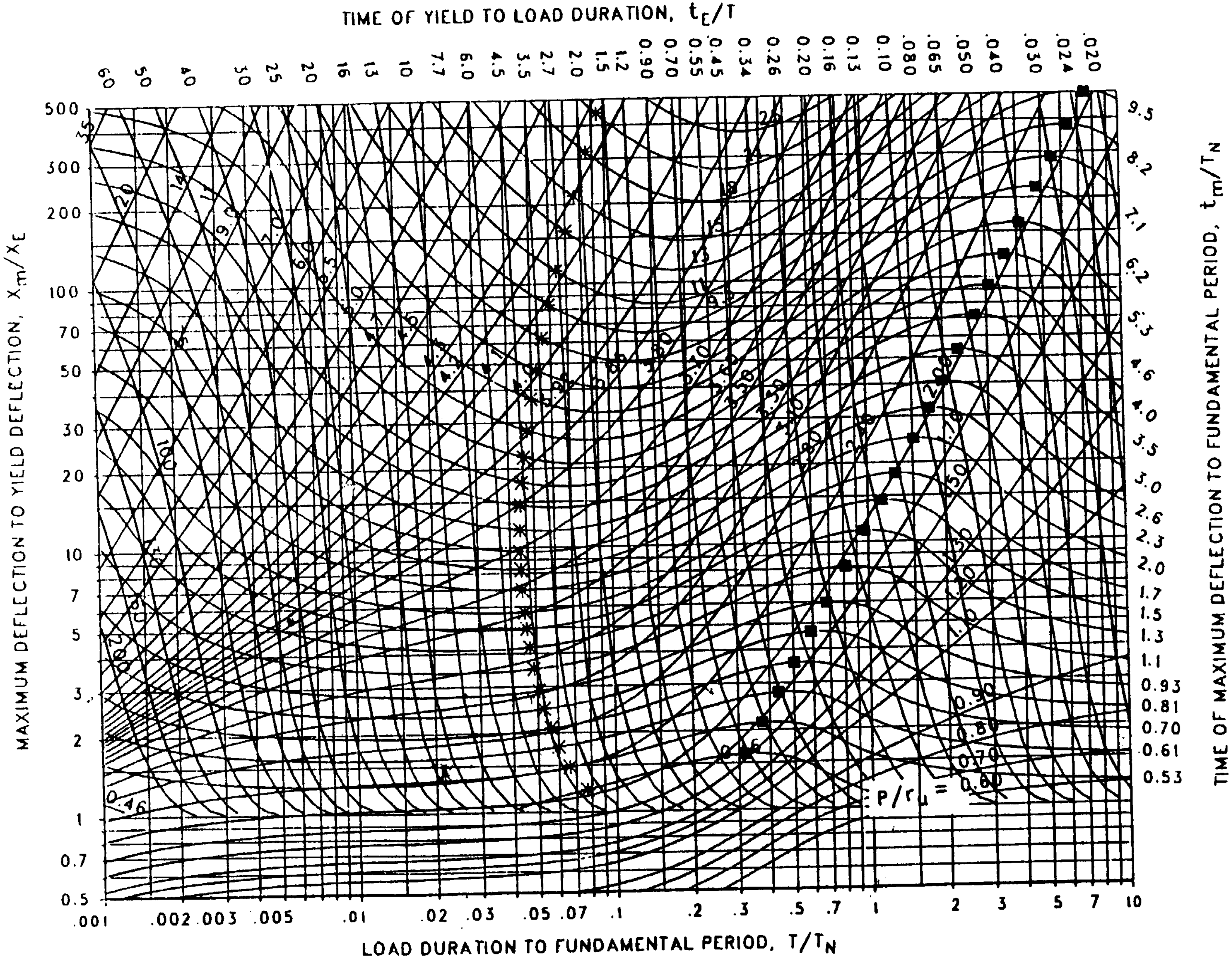


Figure 3-242 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.261, C_2 = 1000.)

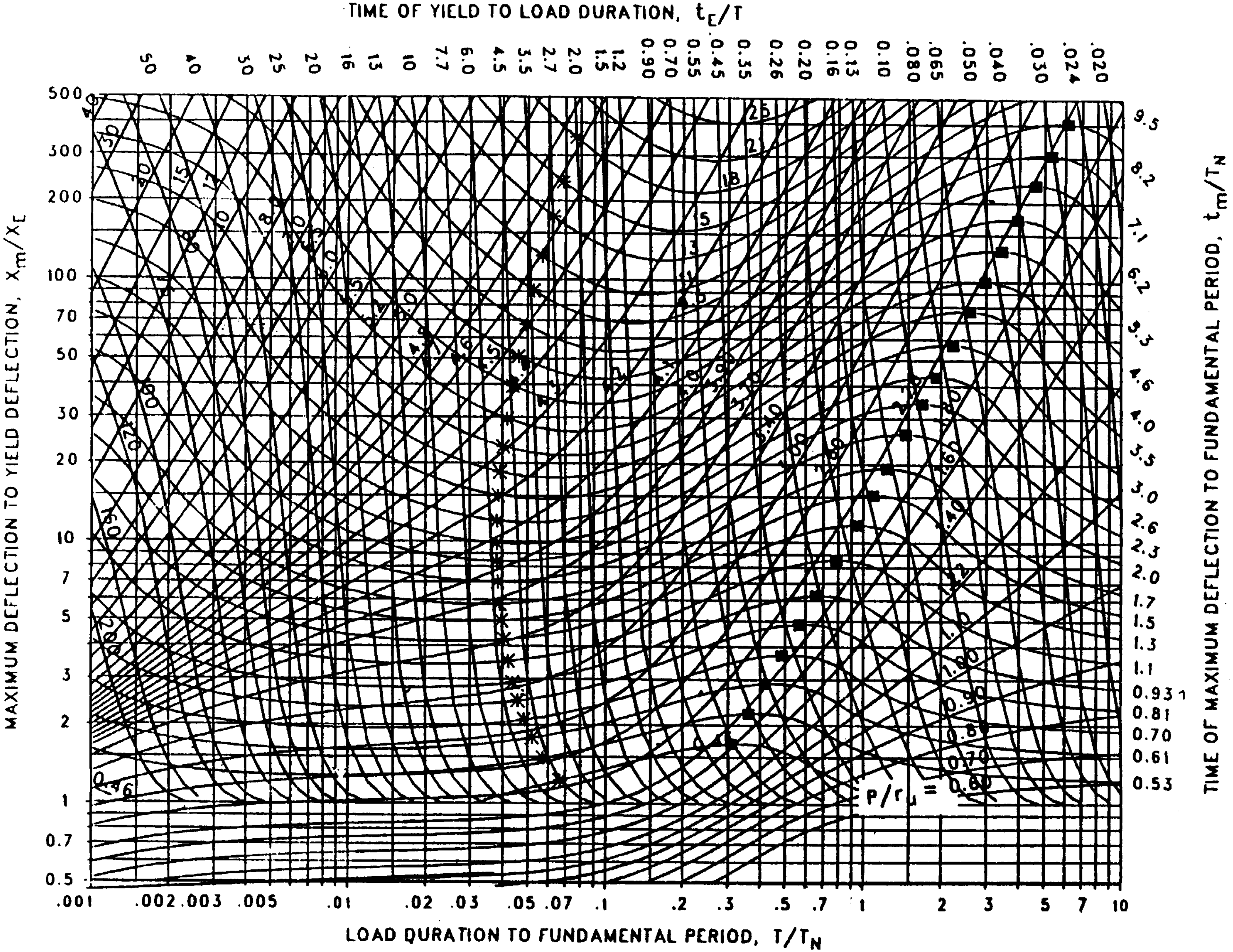


Figure 3-243 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.237, C_2 = 1000.)

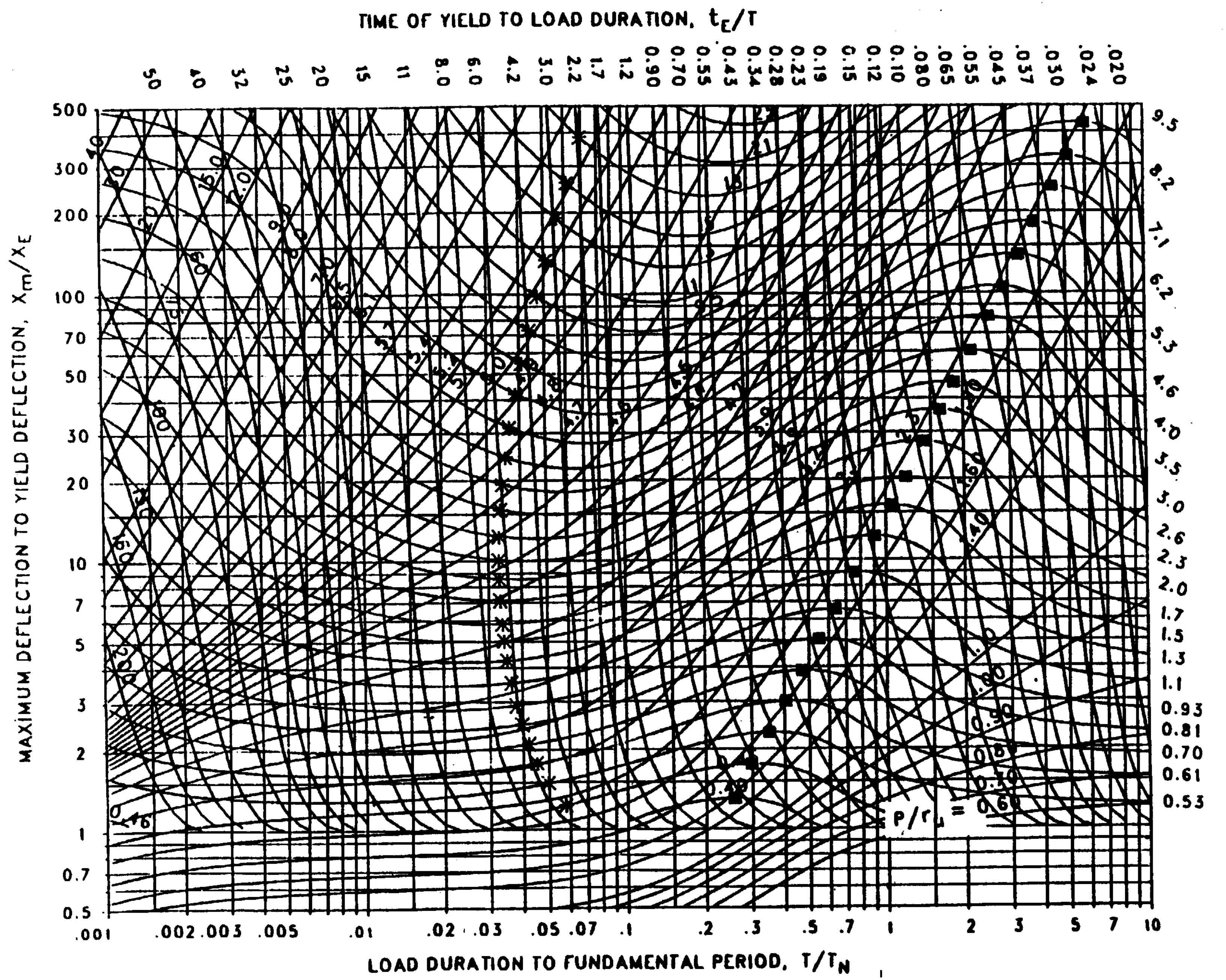


Figure 3-244 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.215, C_2 = 1000.)

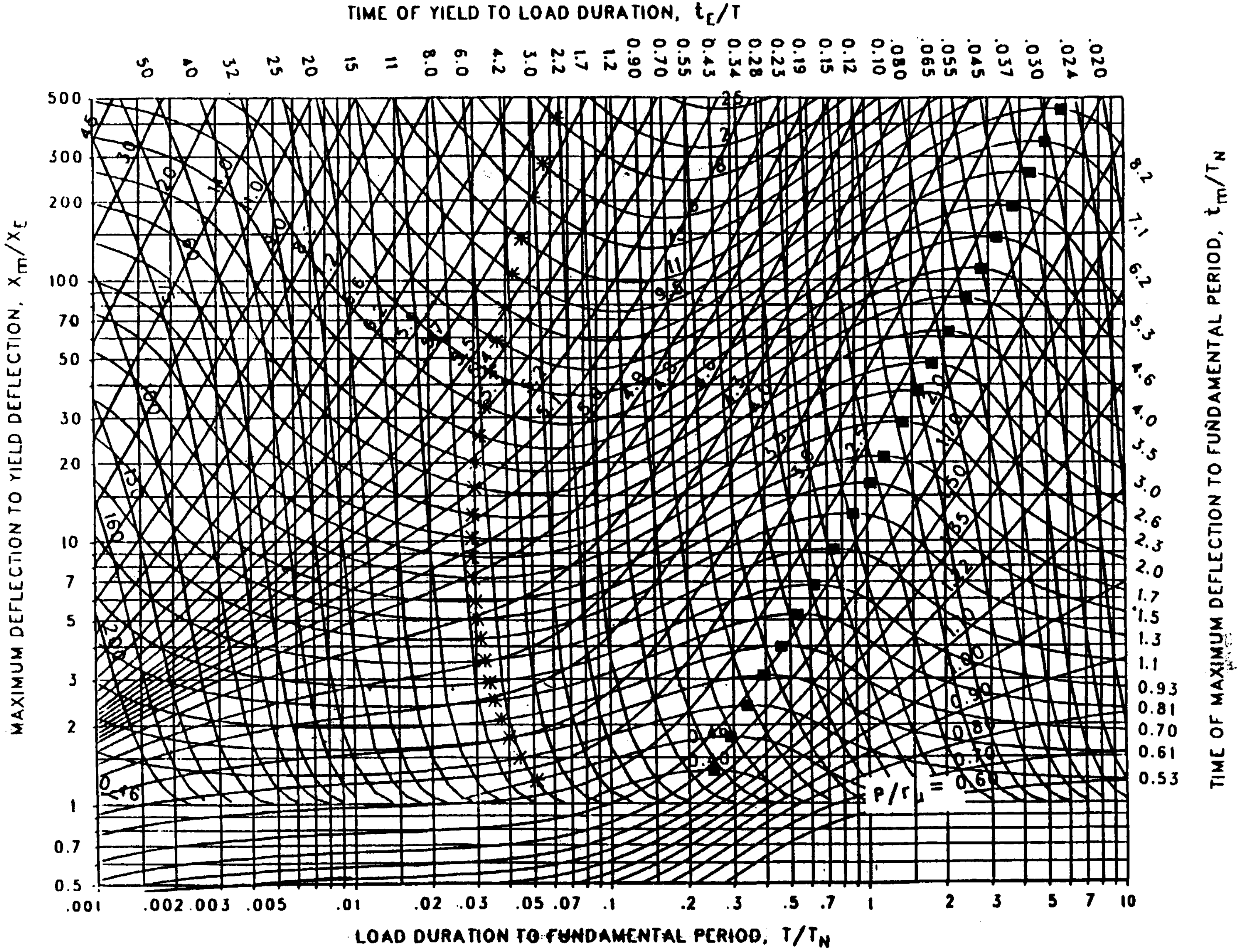


Figure 3-245 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.198, C_2 = 1000.)

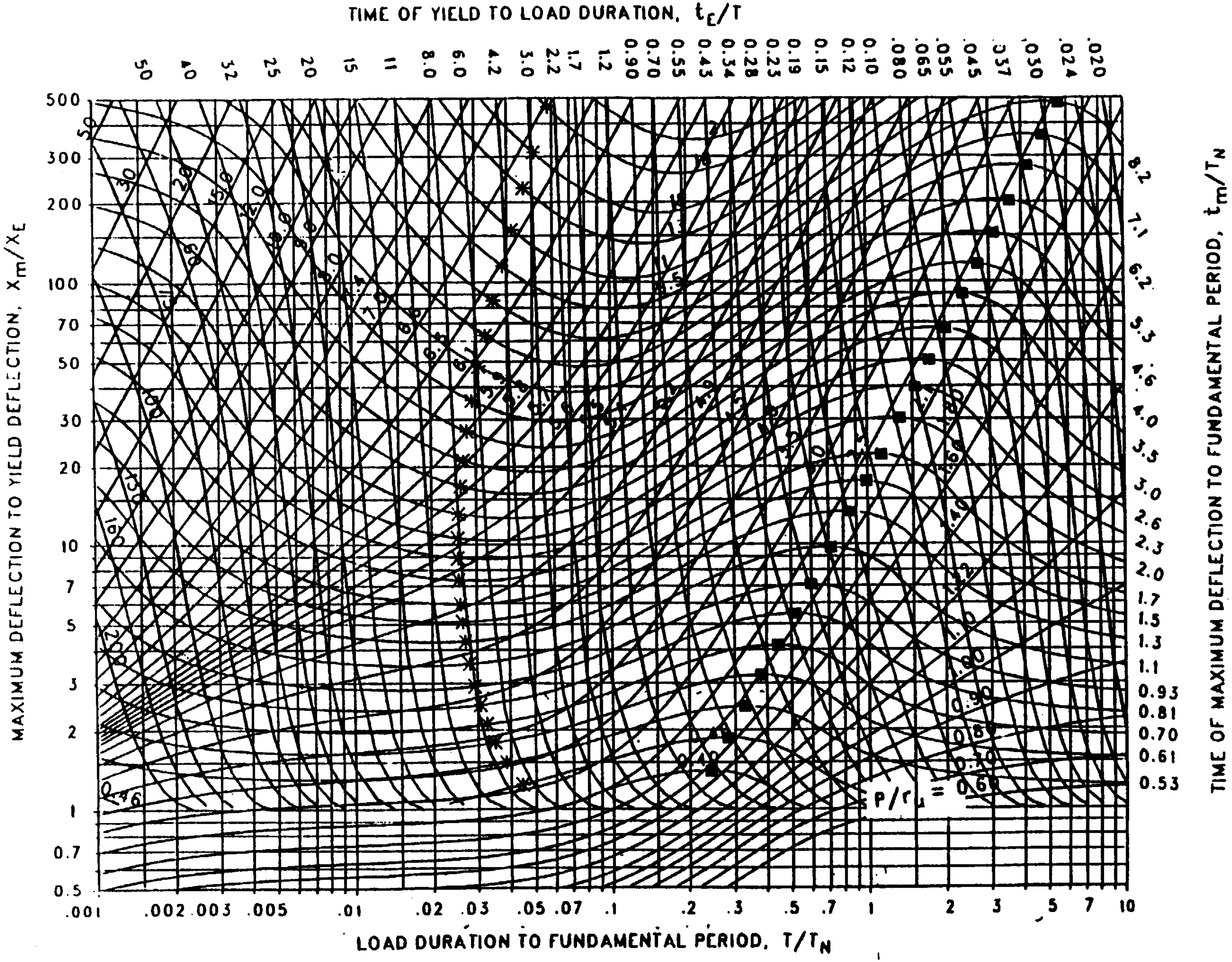


Figure 3-246 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.178, C_2 = 1000.)

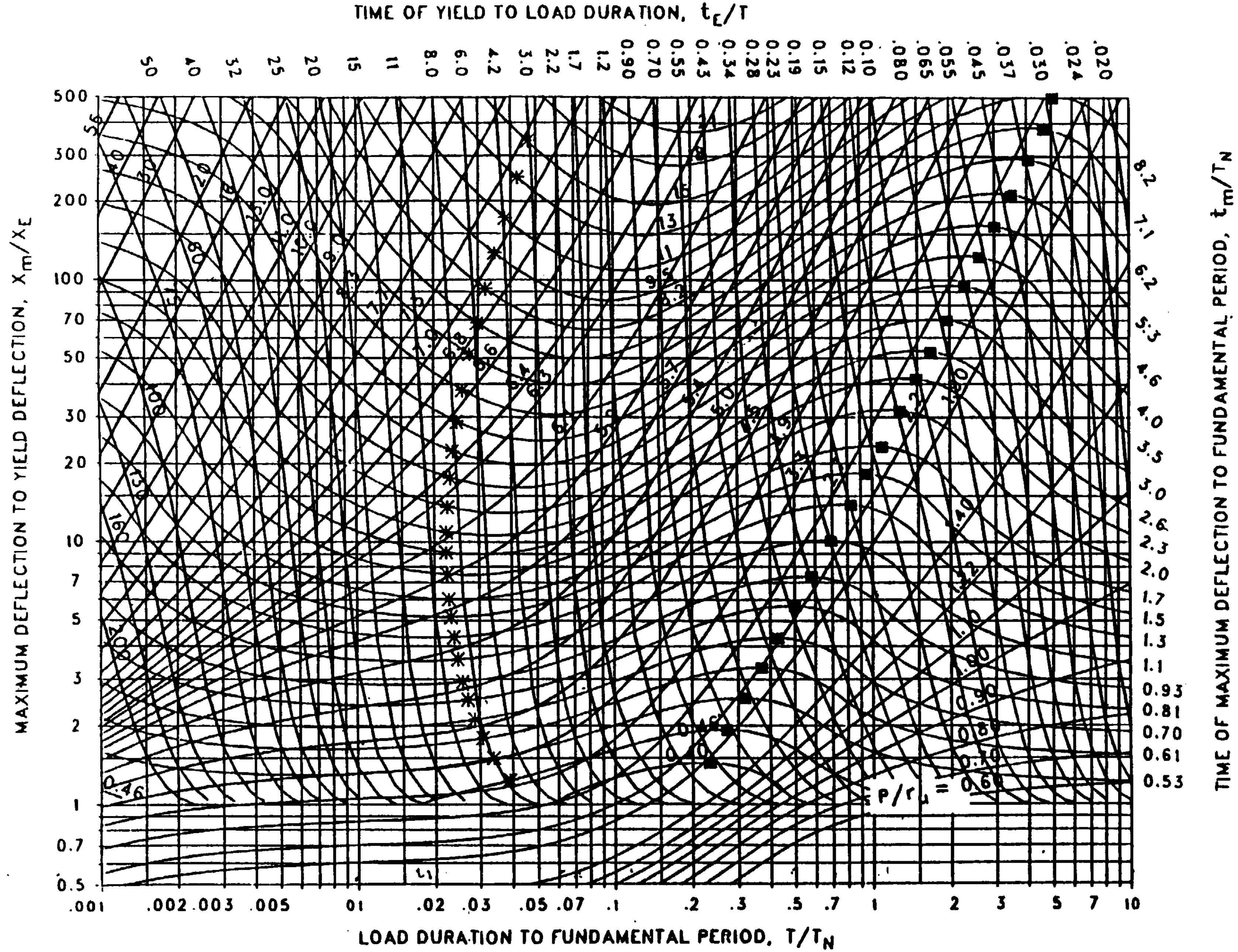


Figure 3-247 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.162, C_2 = 1000.)

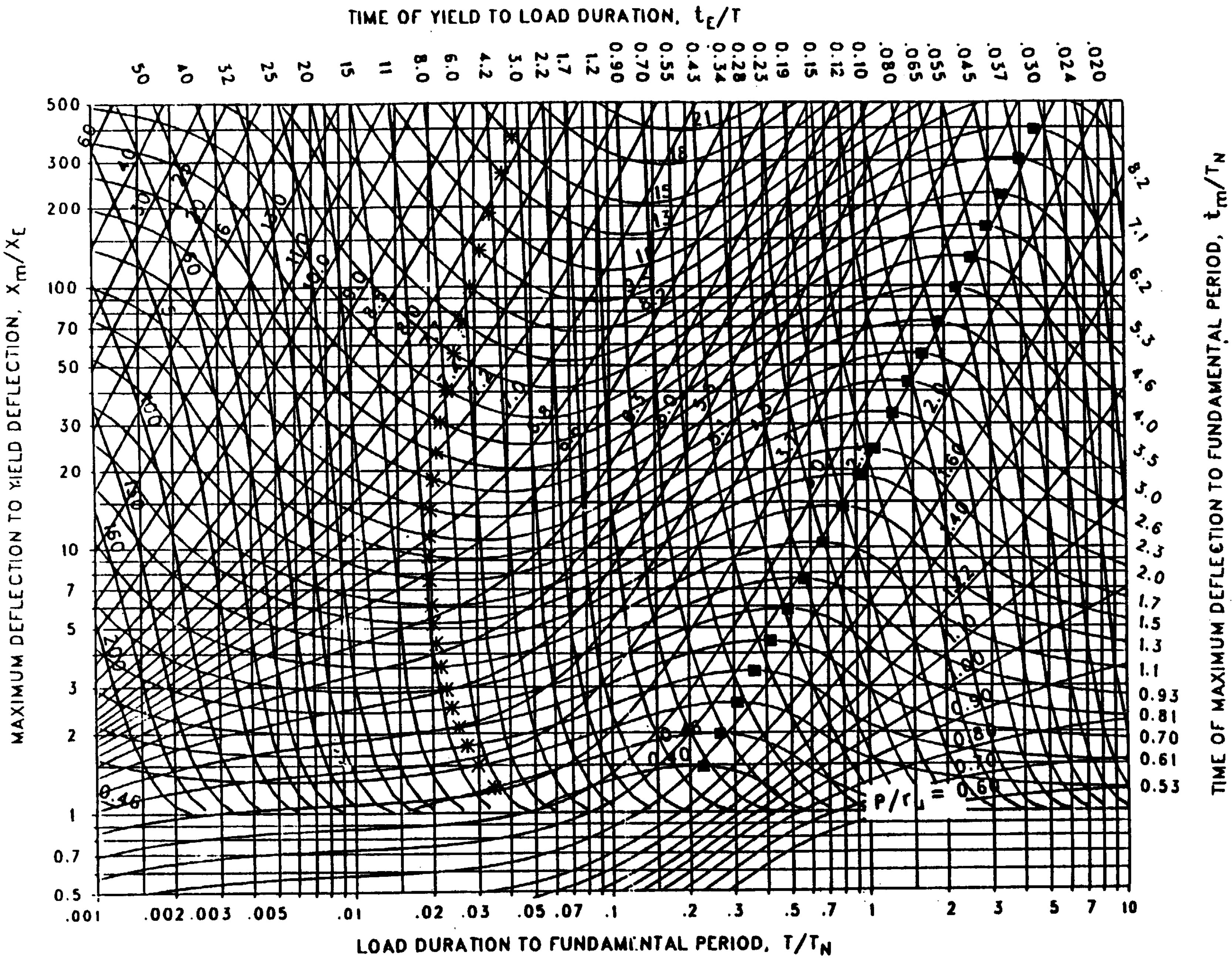


Figure 3-248 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.147, C_2 = 1000.)

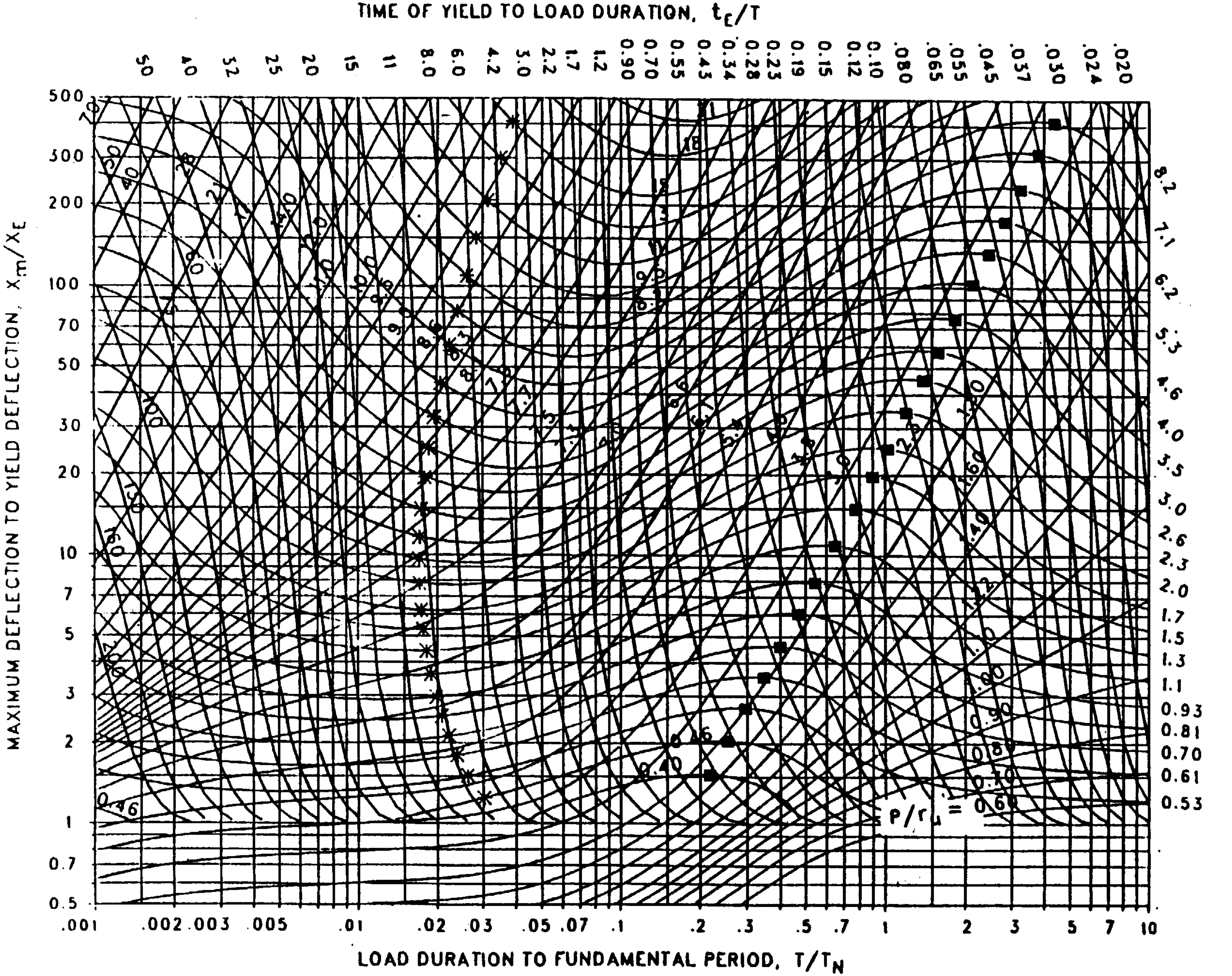


Figure 3-249 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.133, C_2 = 1000.)

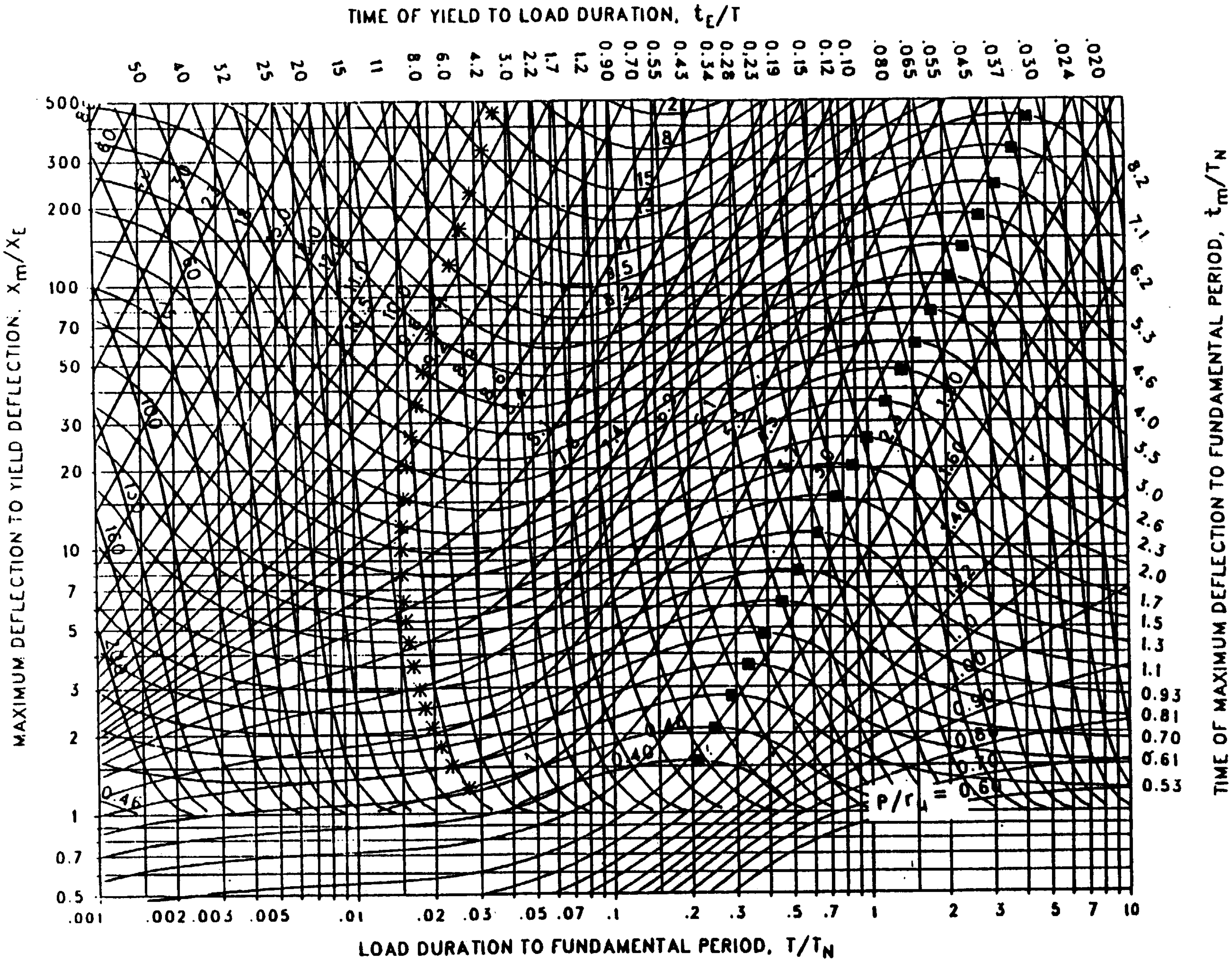


Figure 3-250 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse ($C_1 = 0.121$, $C_2 = 1000.$)

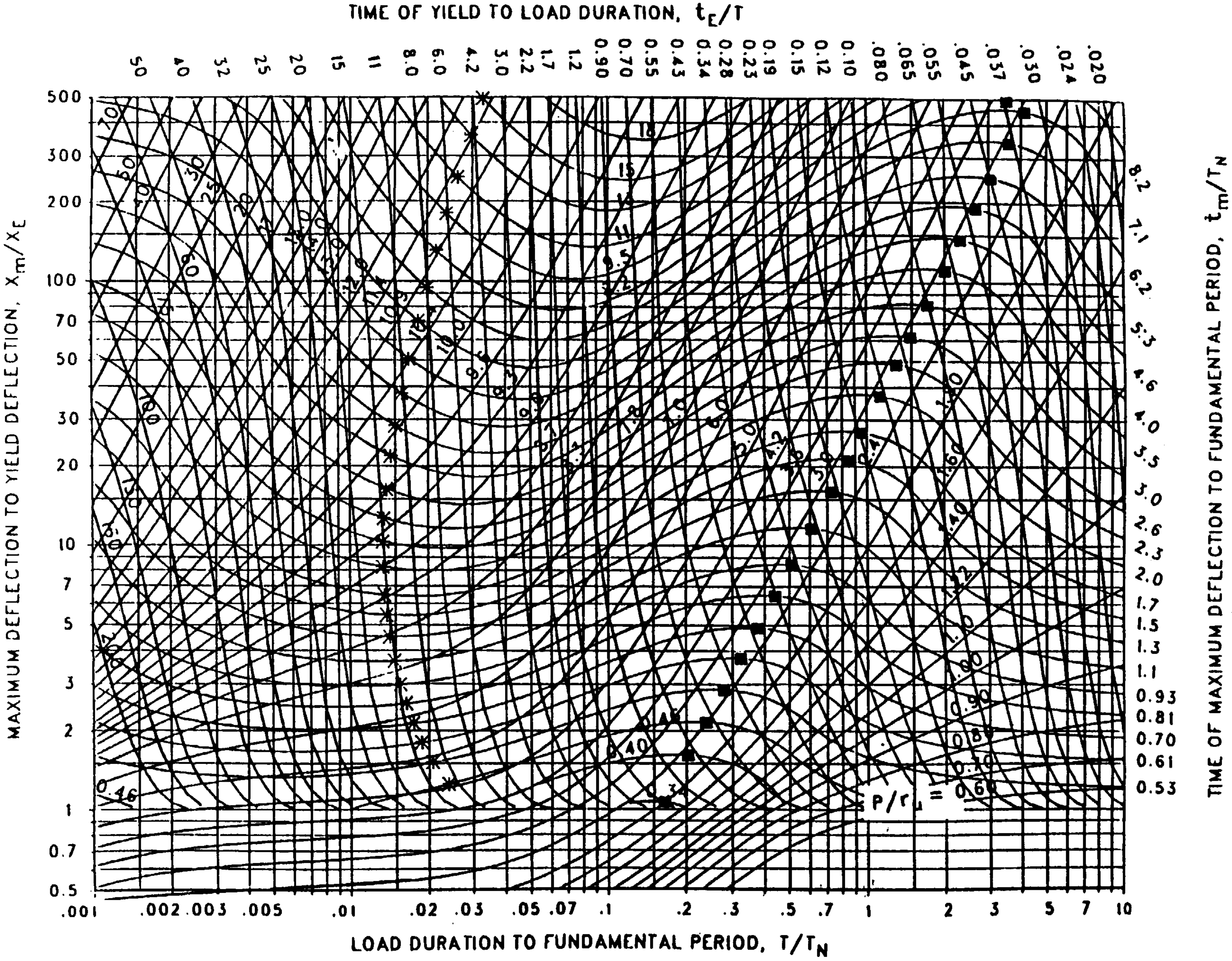


Figure 3-251 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.110, C_2 = 1000.)

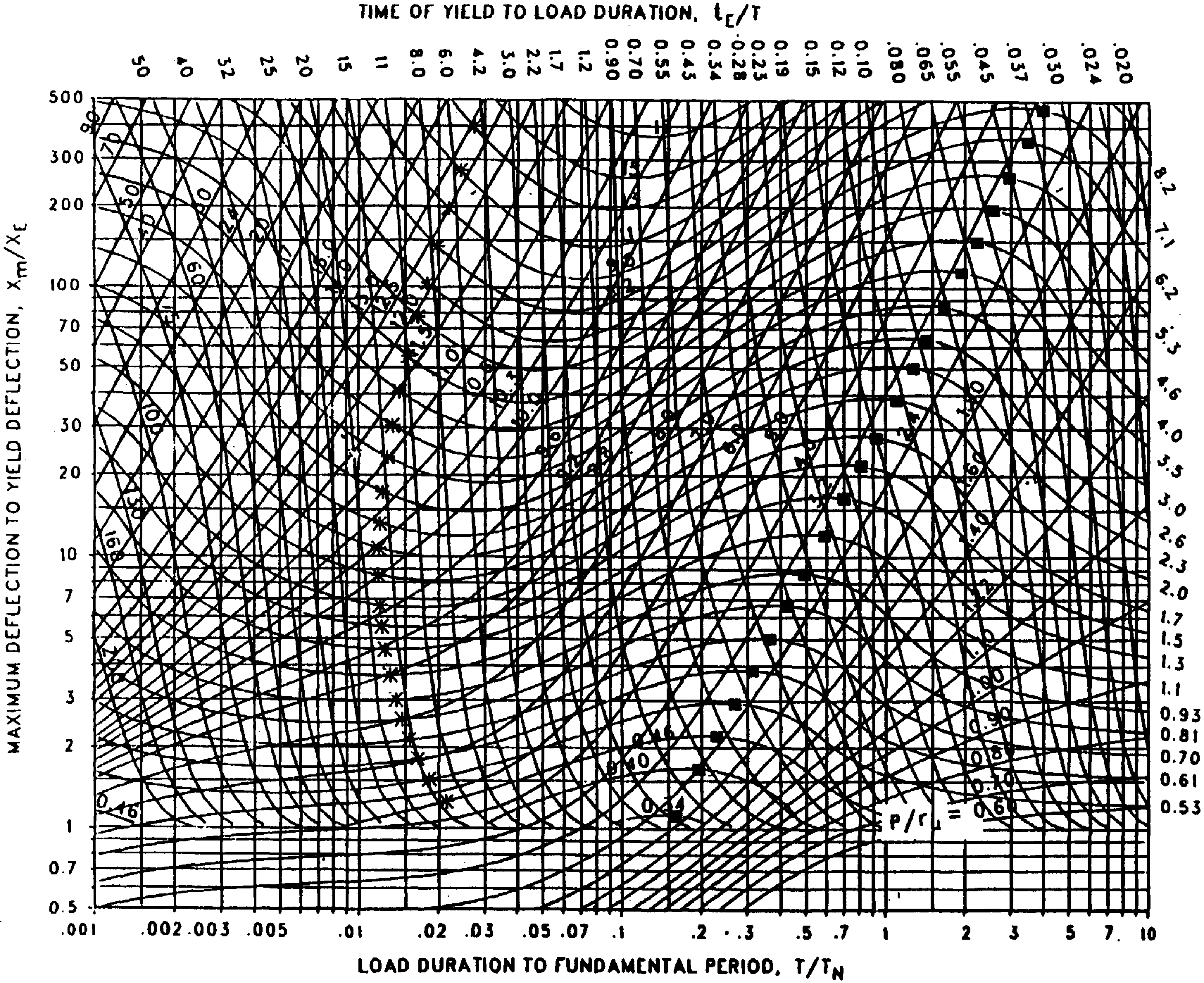


Figure 3-252 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.100, C_2 = 1000.)

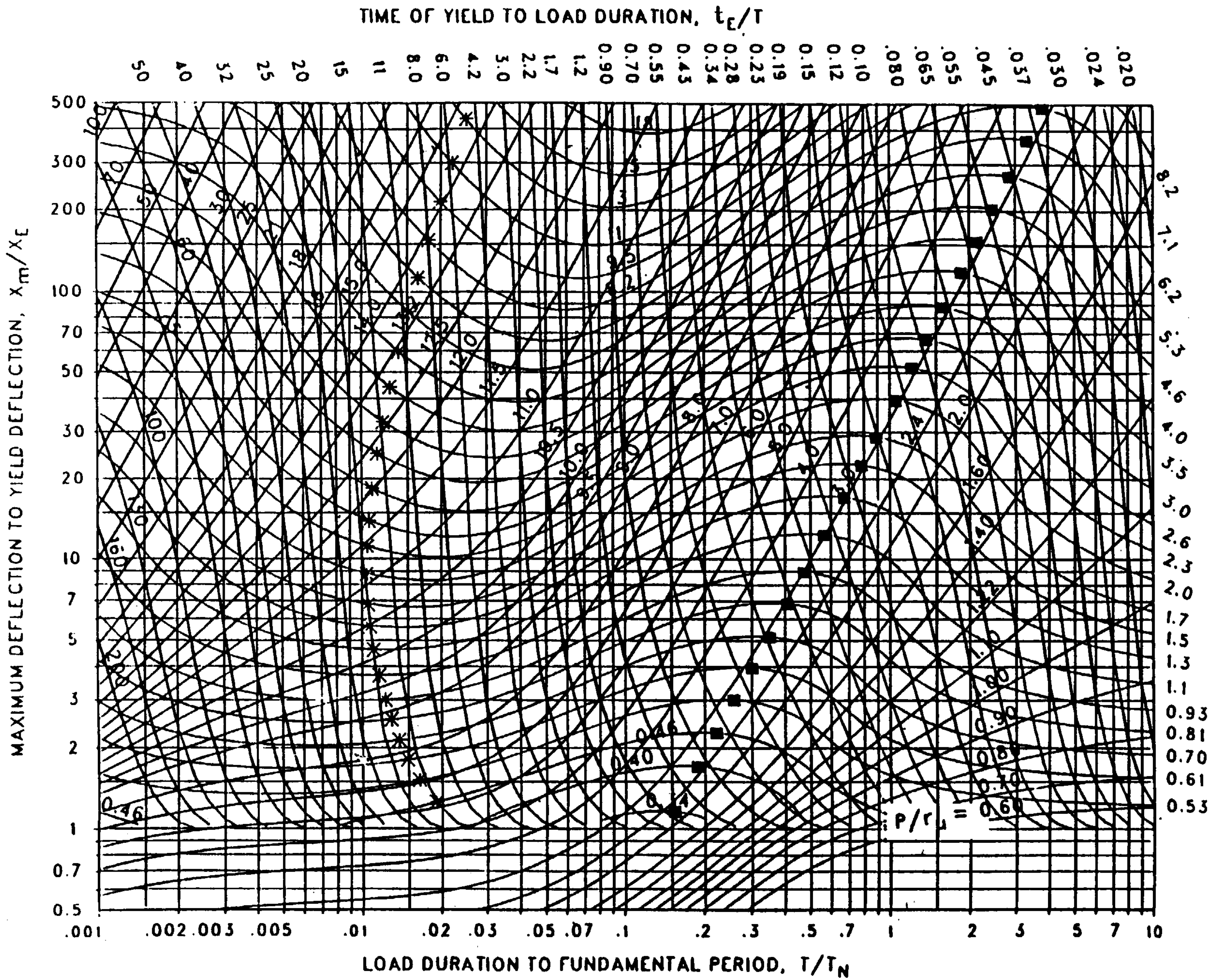


Figure 3-253 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.091, C_2 = 1000.)

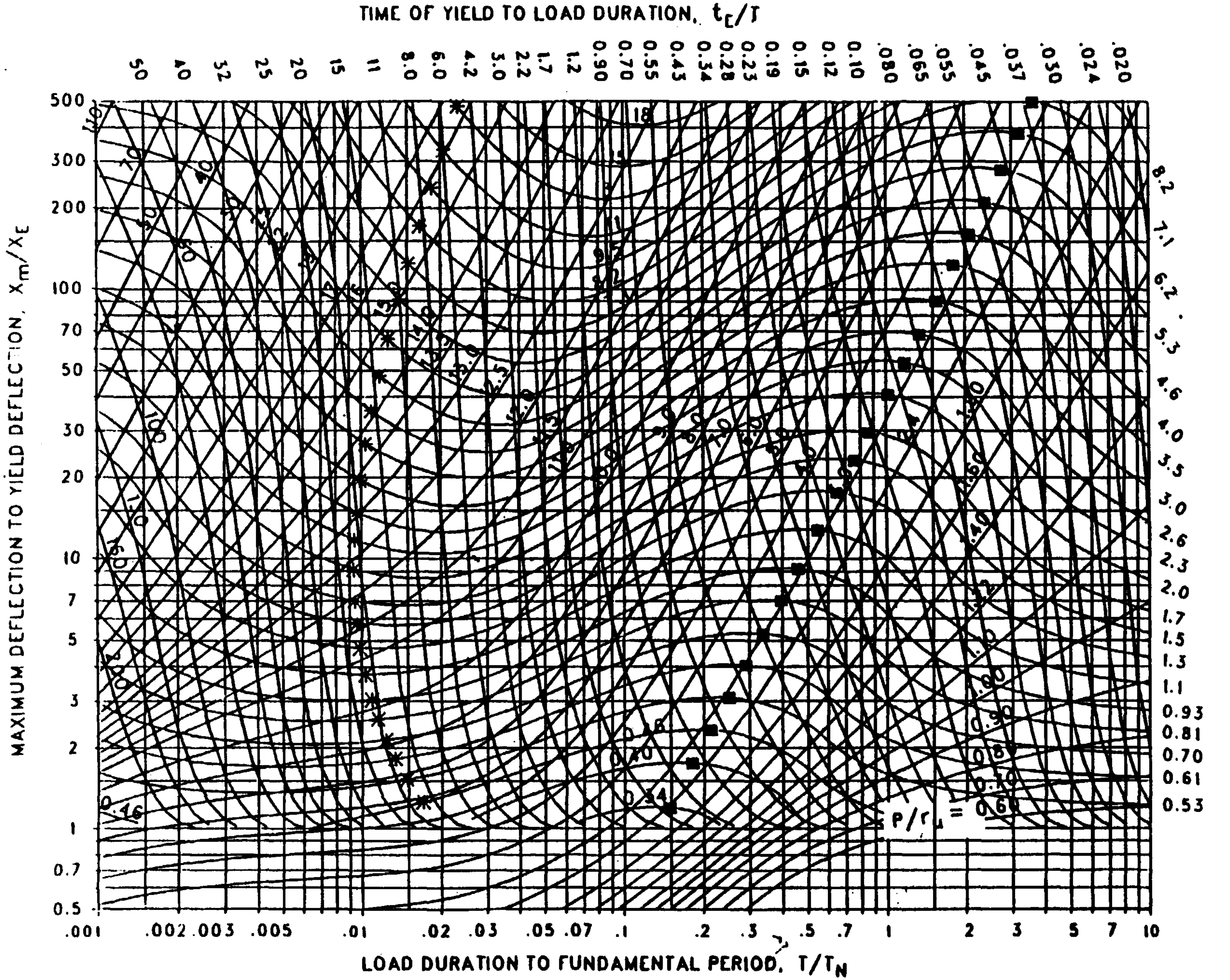


Figure 3-254 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.083, C_2 = 1000.)

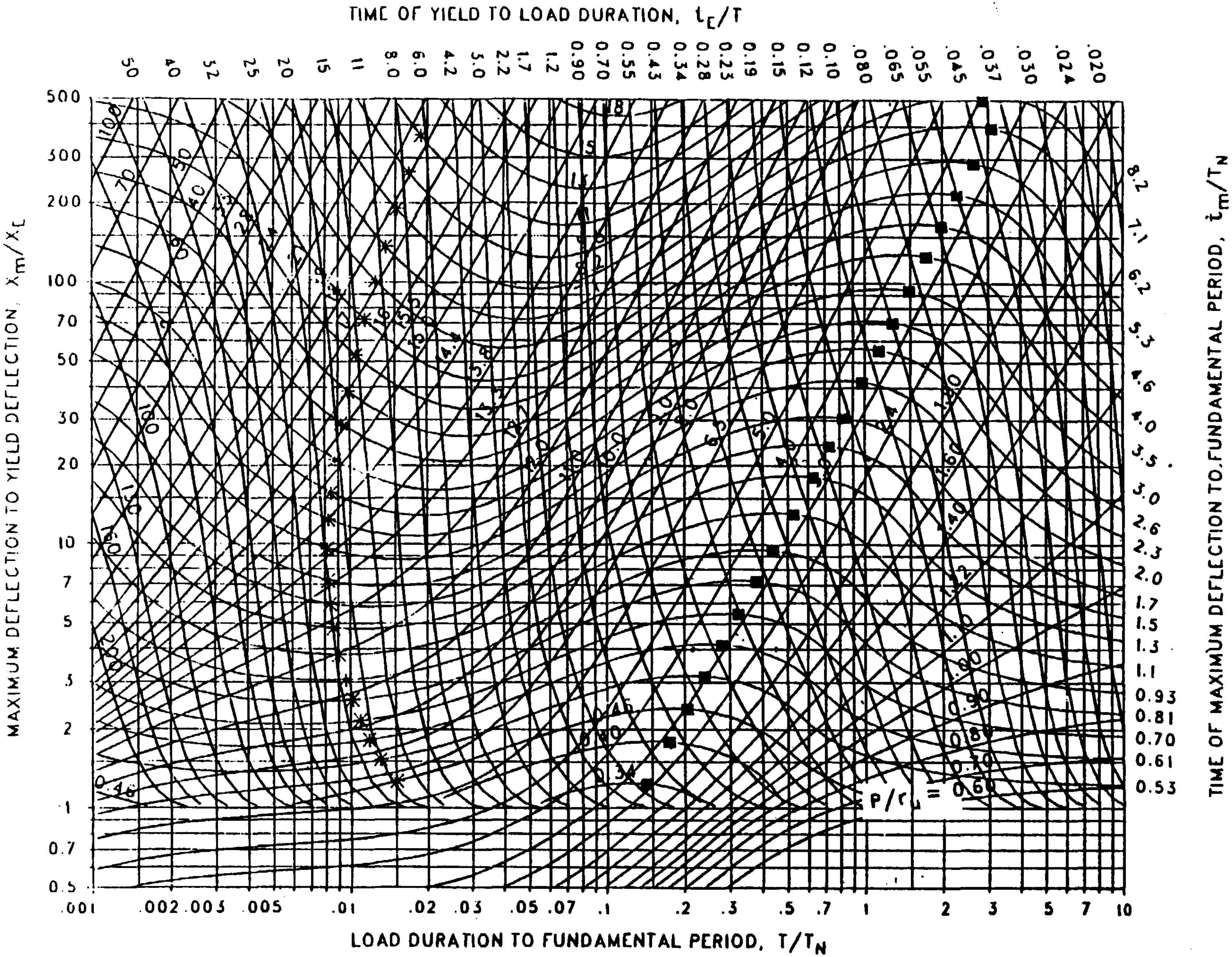


Figure 3-255. Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.075, C_2 = 1000.)

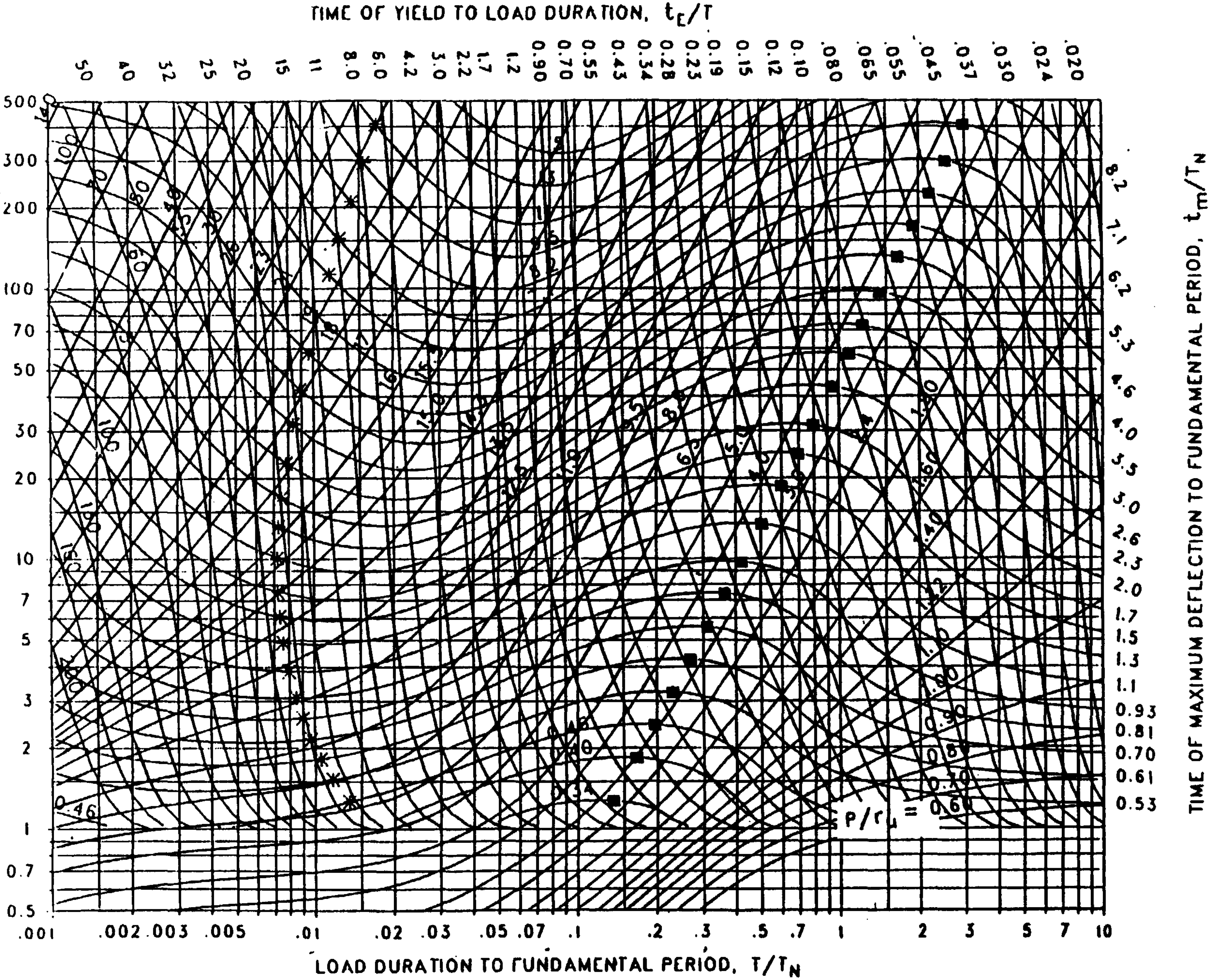


Figure 3-256 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.068, C_2 = 1000.)

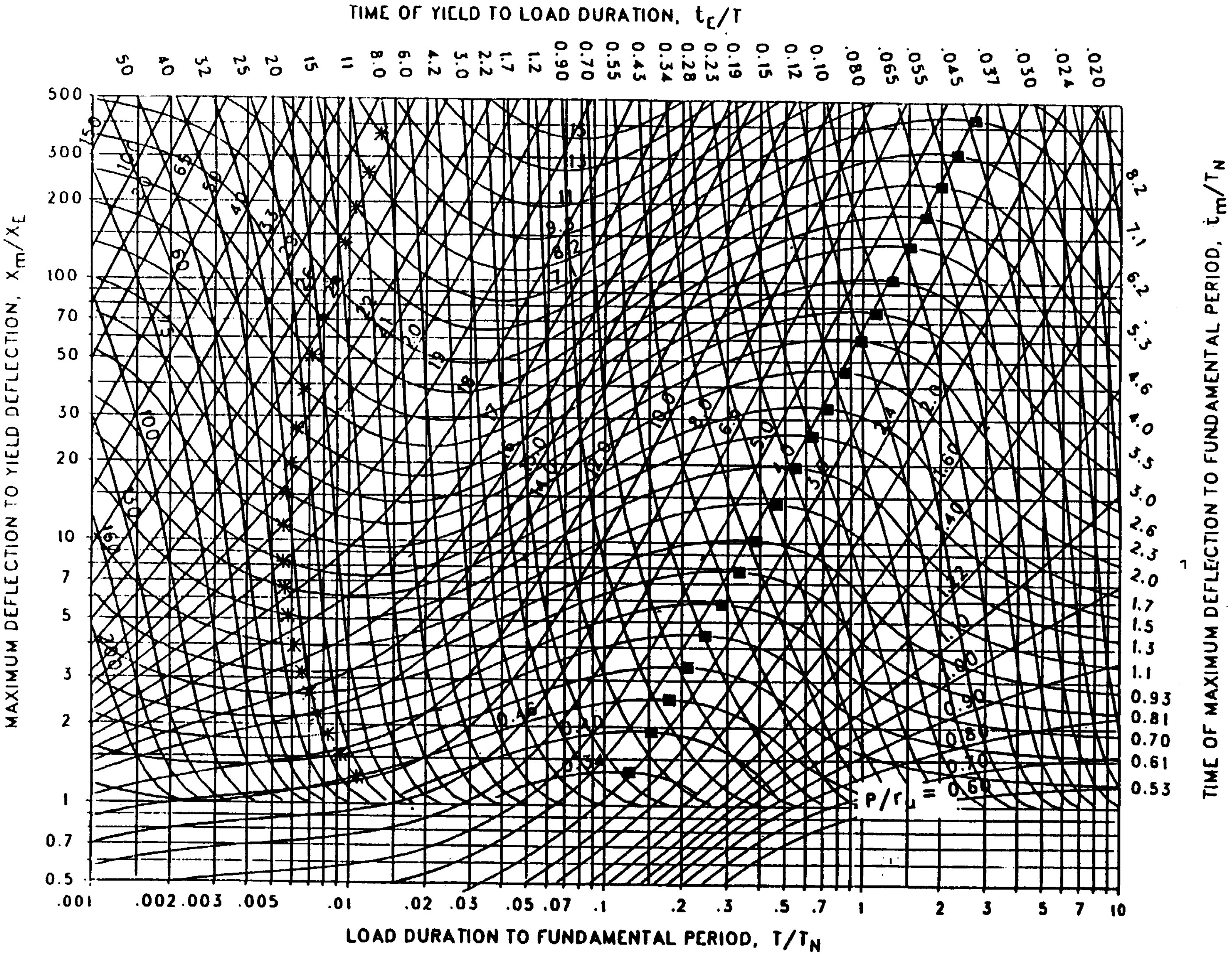


Figure 3-257 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.056, C_2 = 1000.)

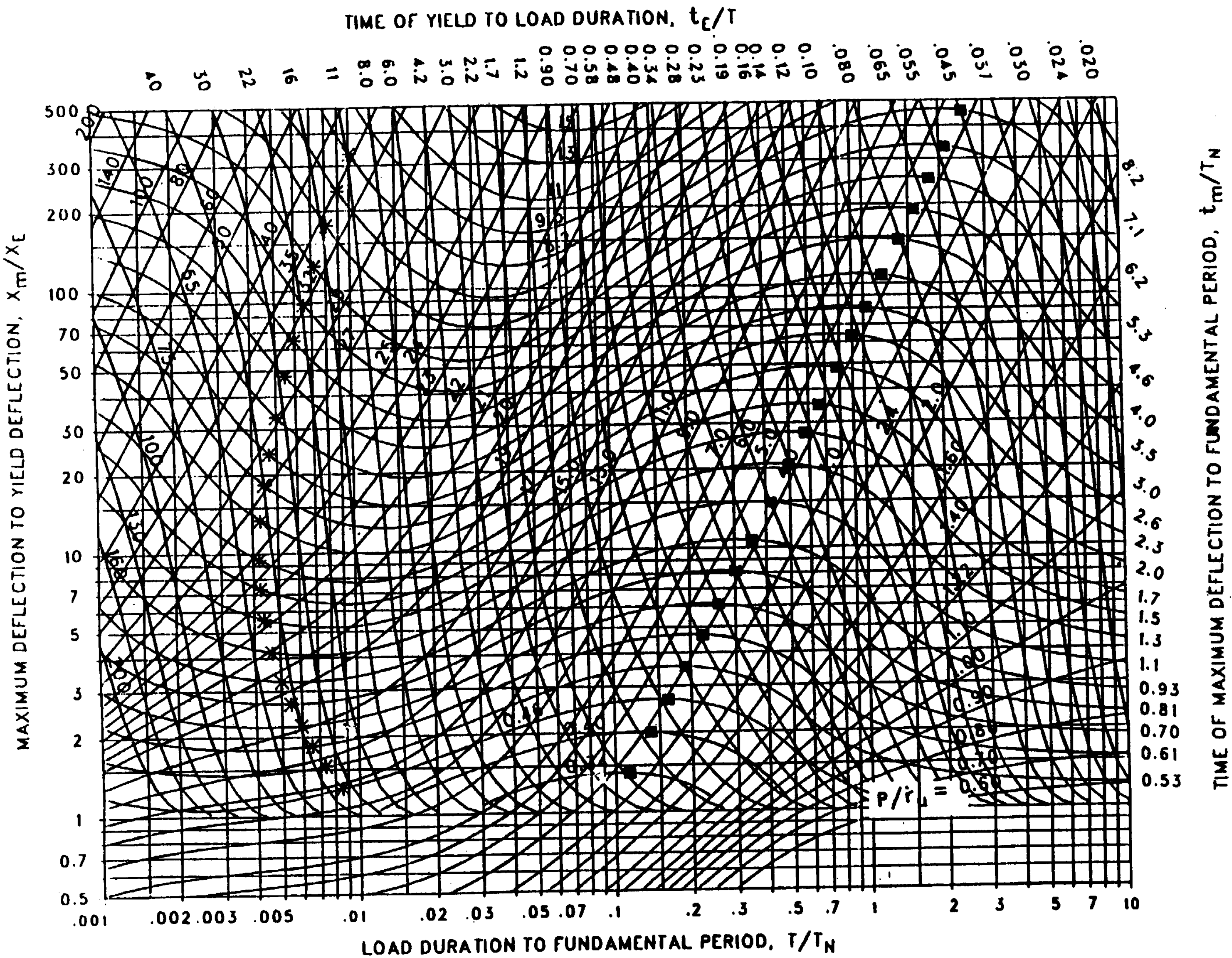


Figure 3-258 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.046, C_2 = 1000.)

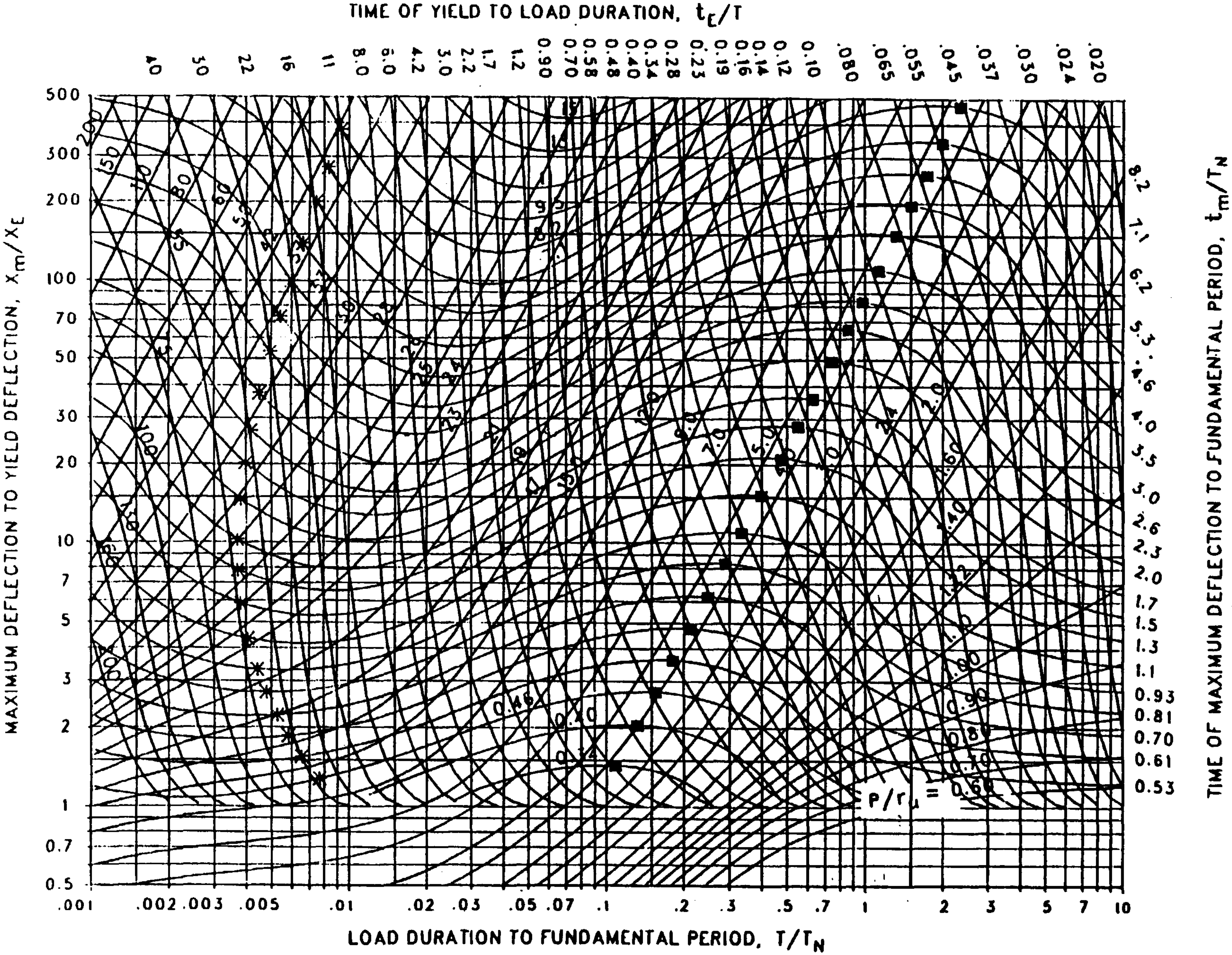


Figure 3-259 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.042, C_2 = 1000.)

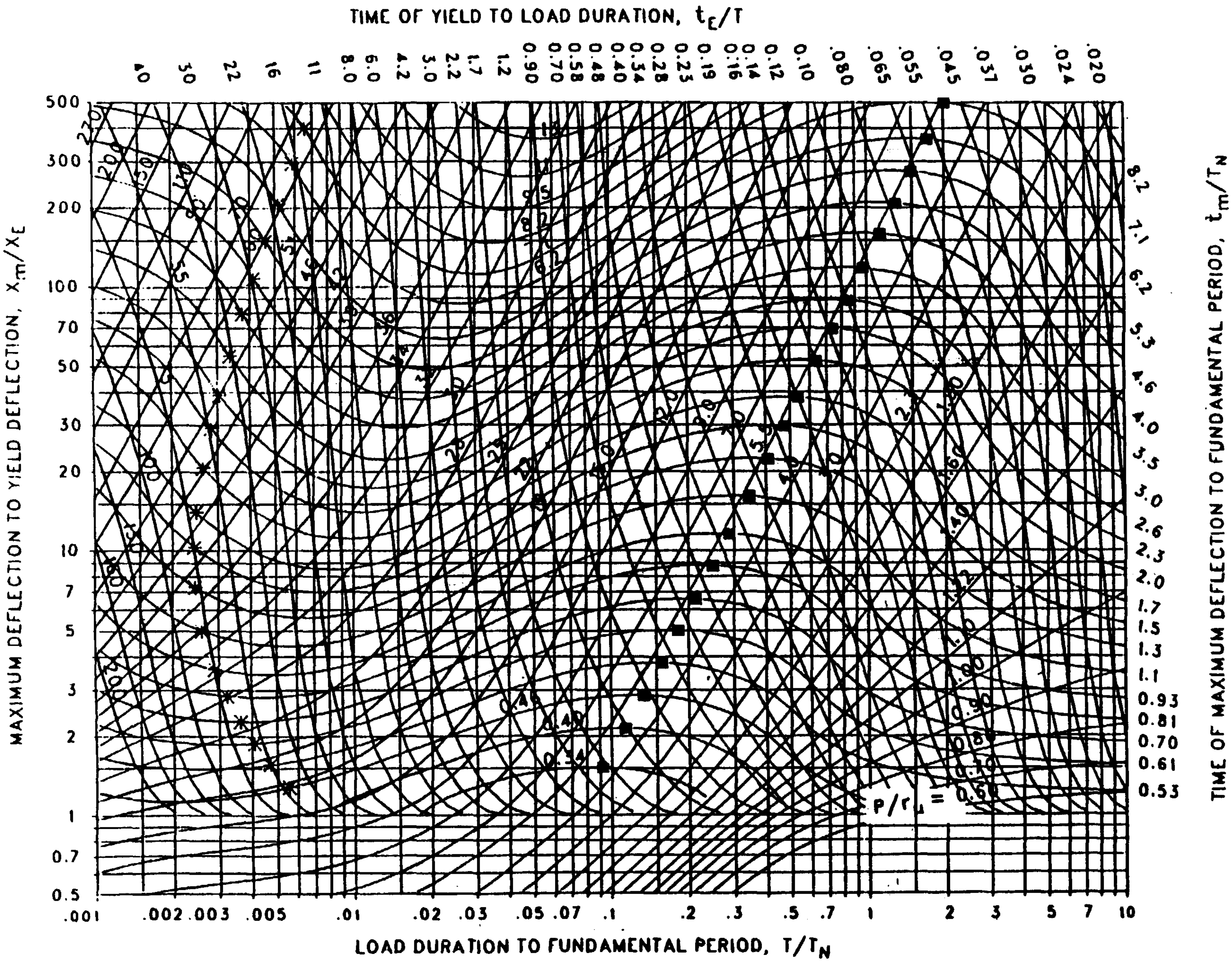


Figure 3-260 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.032, C_2 = 1000.)

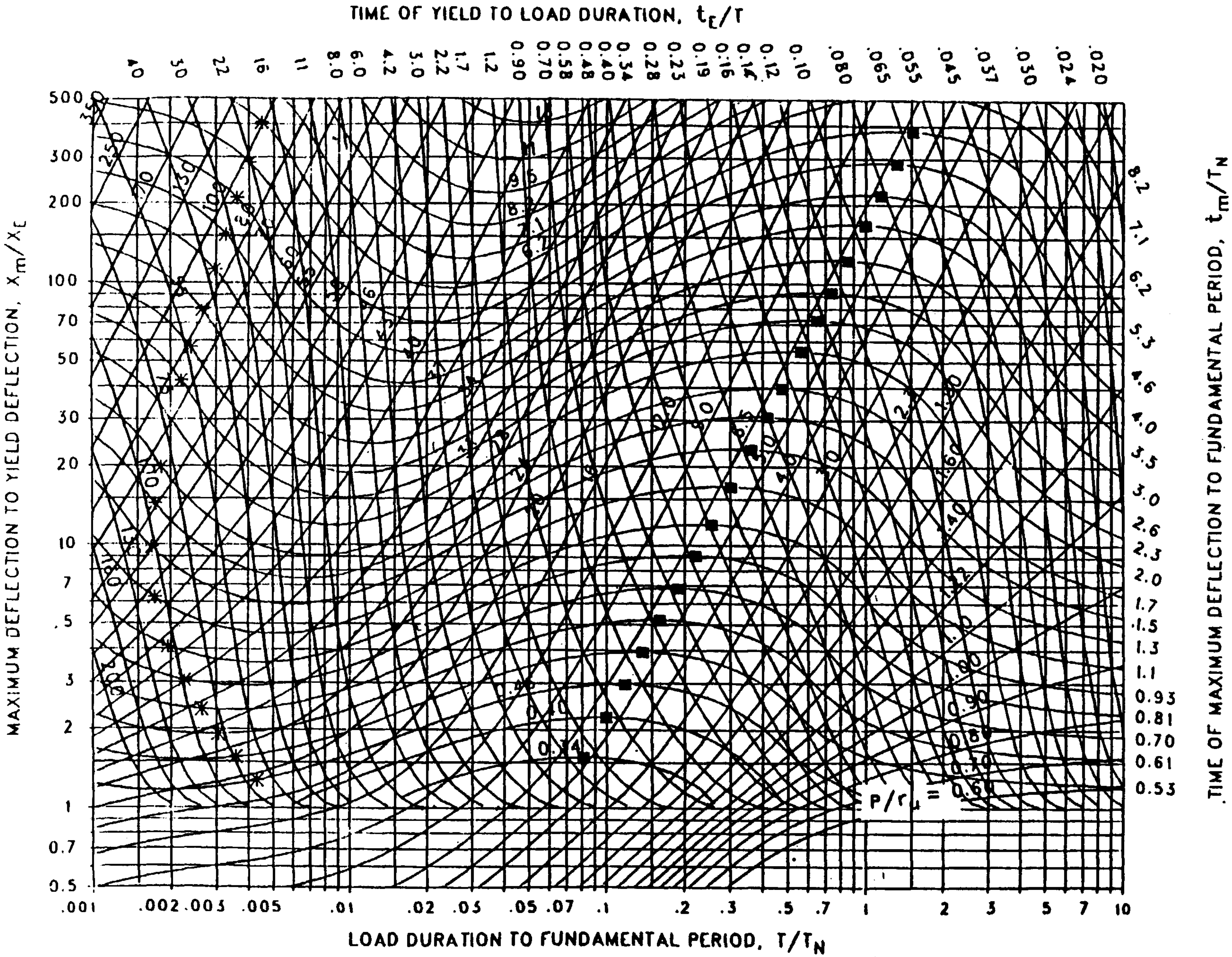


Figure 3-261 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.026, C_2 = 1000.)

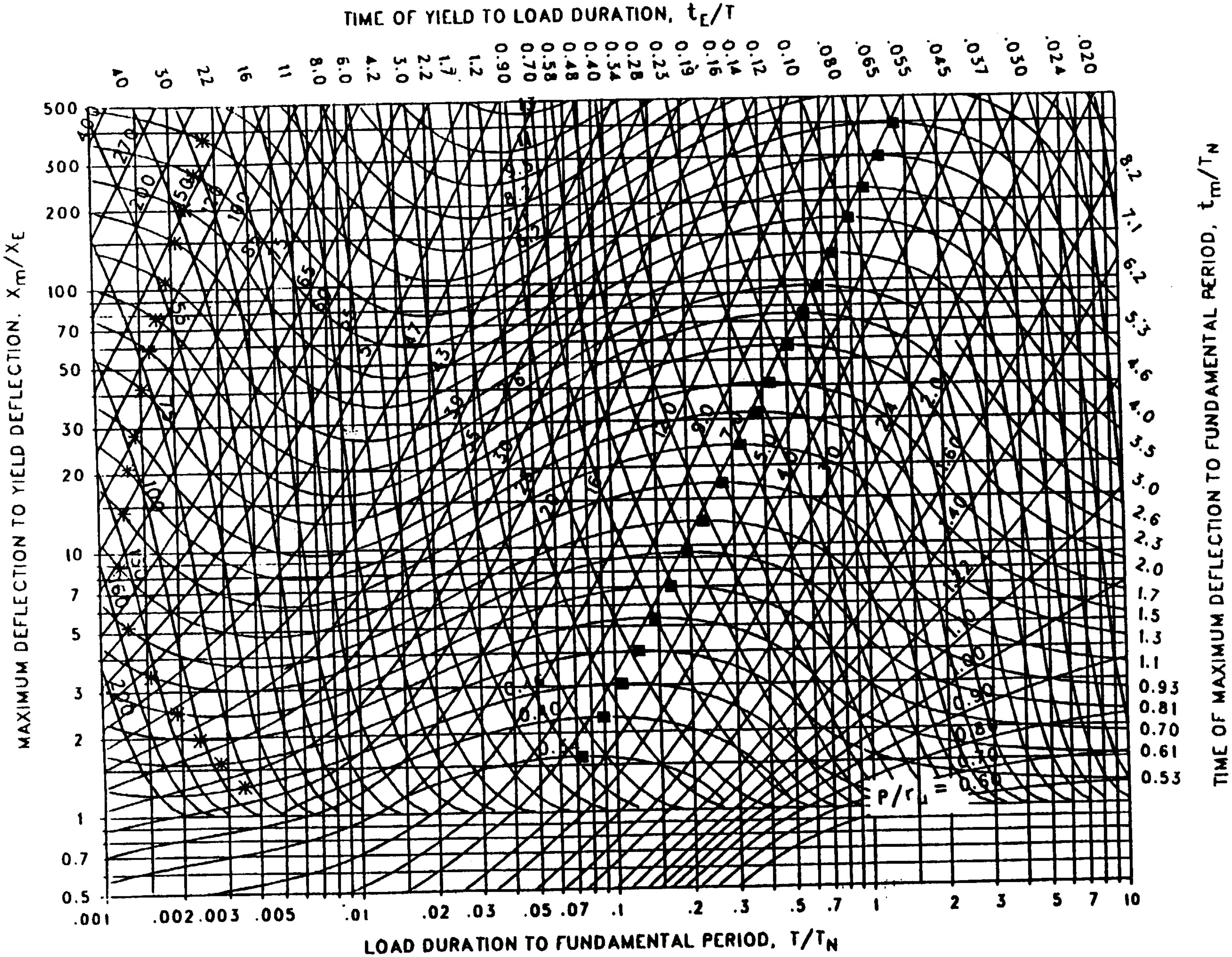


Figure 3-262 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.022, C_2 = 1000.)

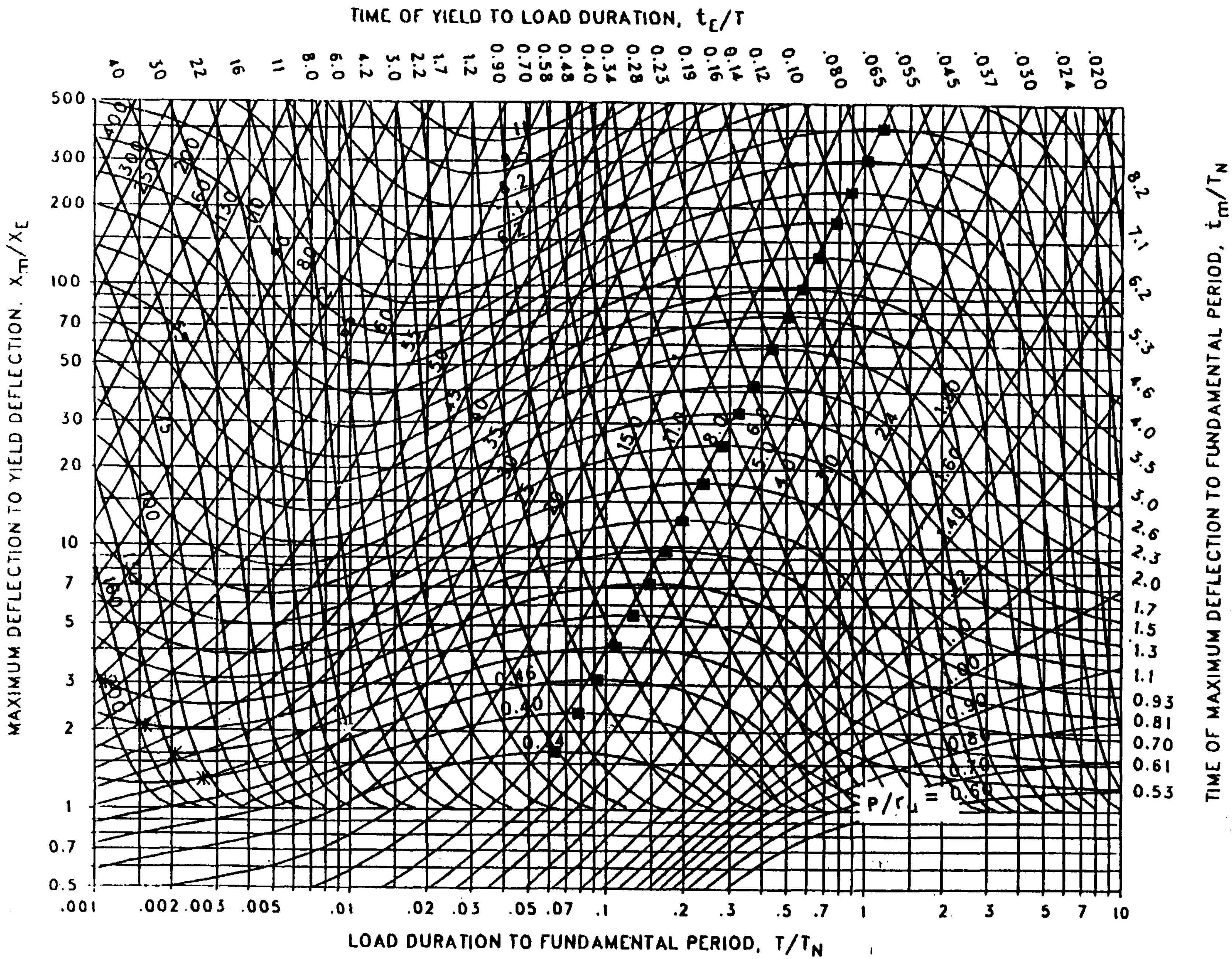


Figure 3-263 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.018, C_2 = 1000.)

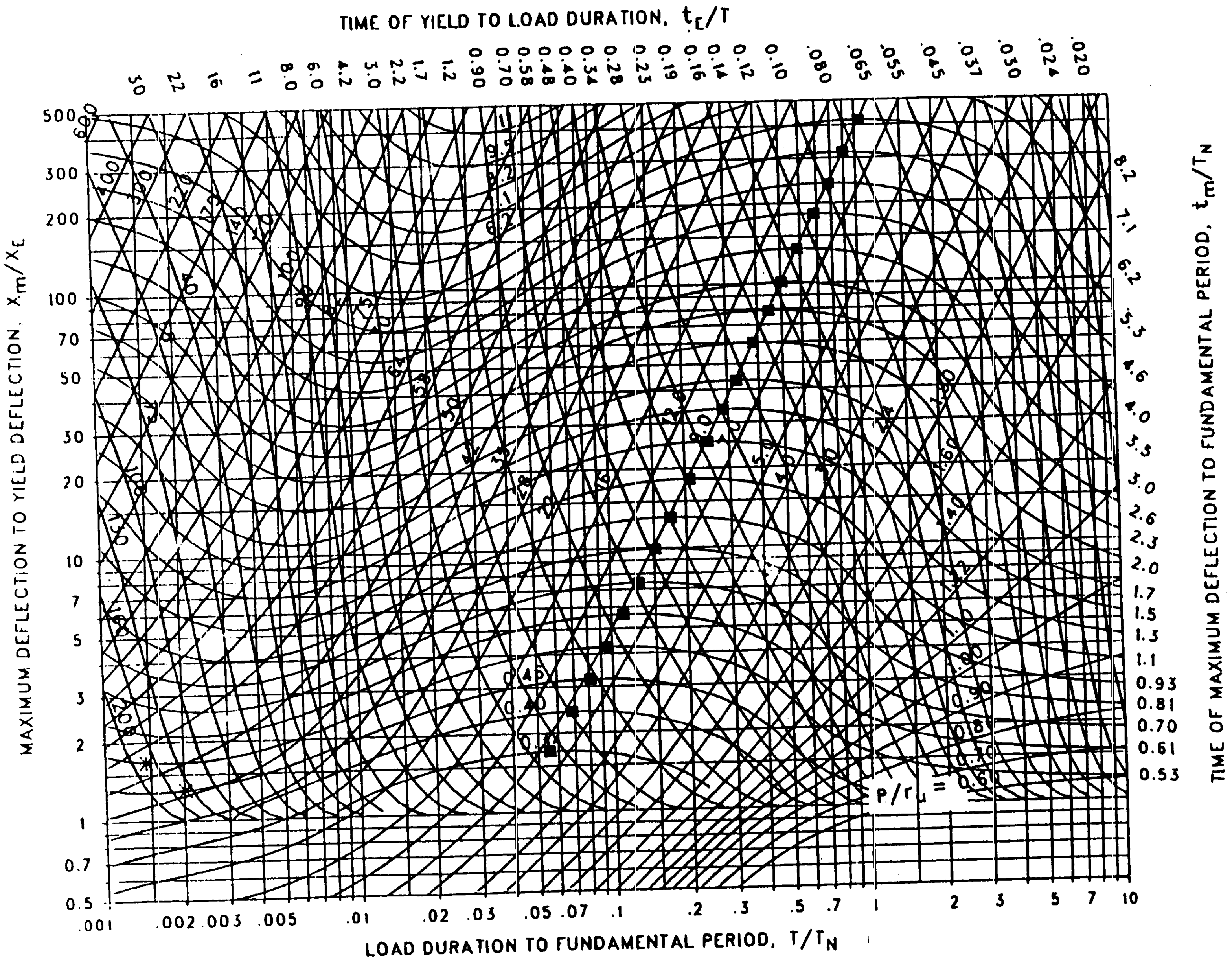


Figure 3-264 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.015, C_2 = 1000.)

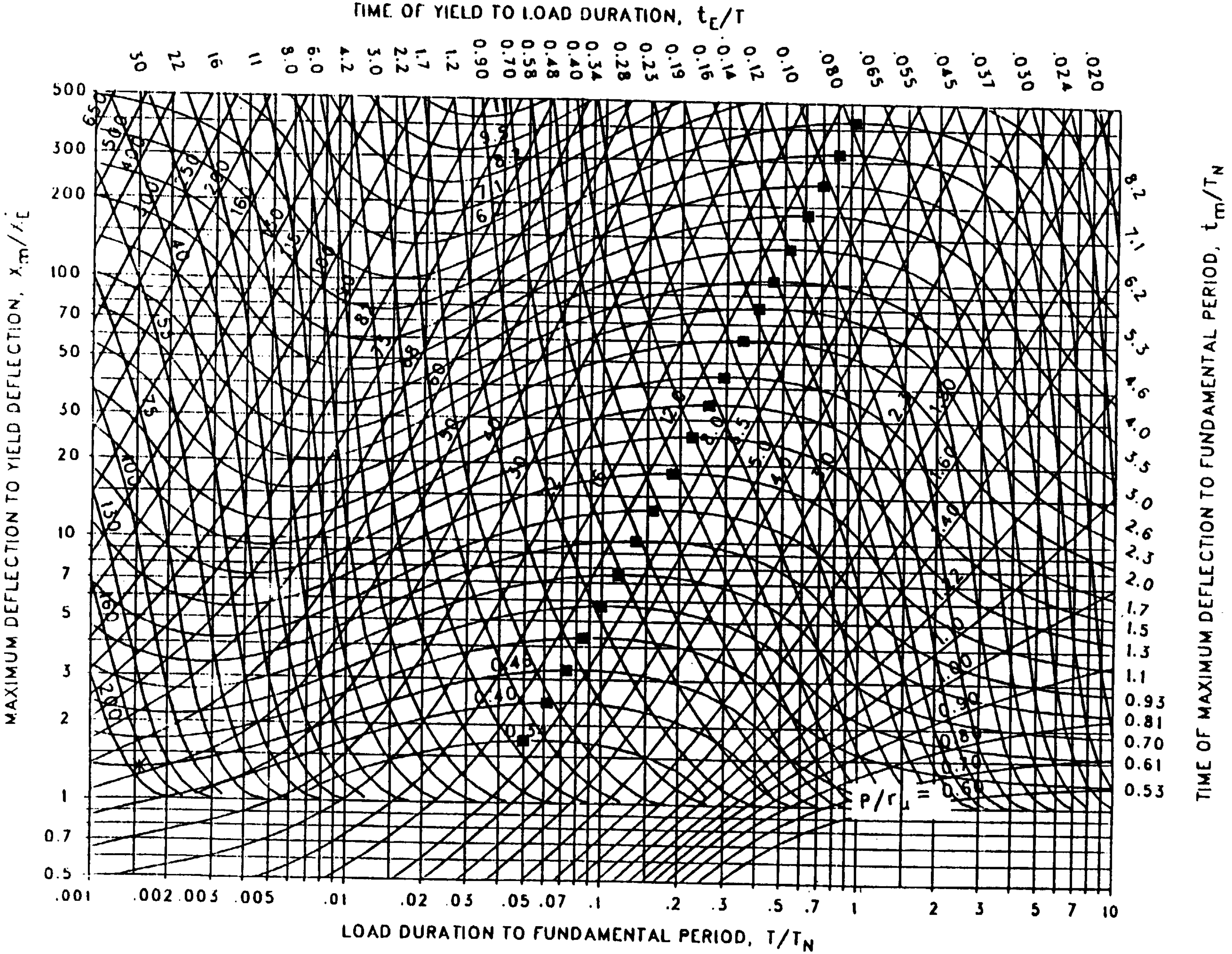


Figure 3-265 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.013, C_2 = 1000.)

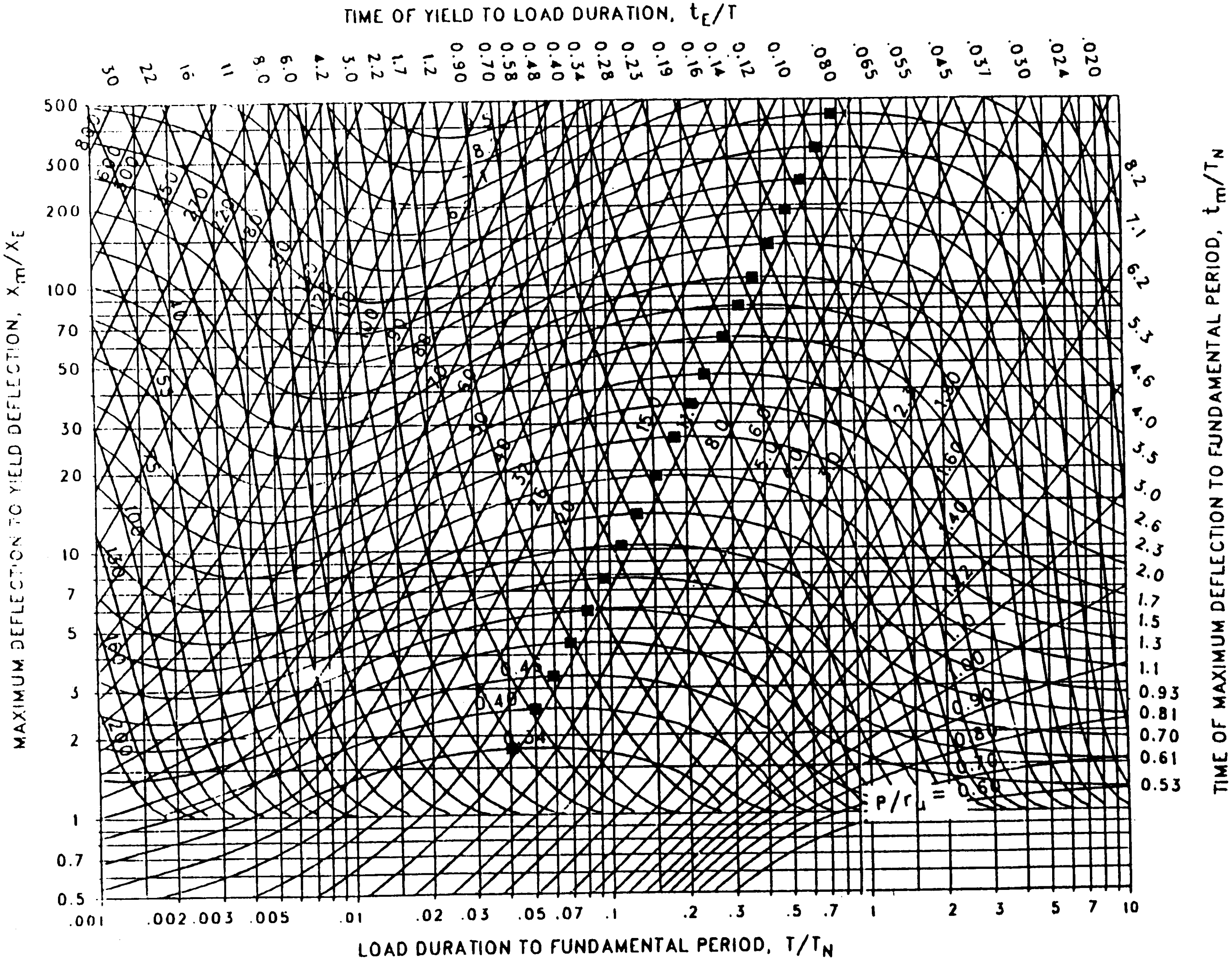


Figure 3-266 Maximum response of elasto-plastic, one-degree-of-freedom system for bilinear-triangular pulse (C_1 = 0.010, C_2 = 1000.)

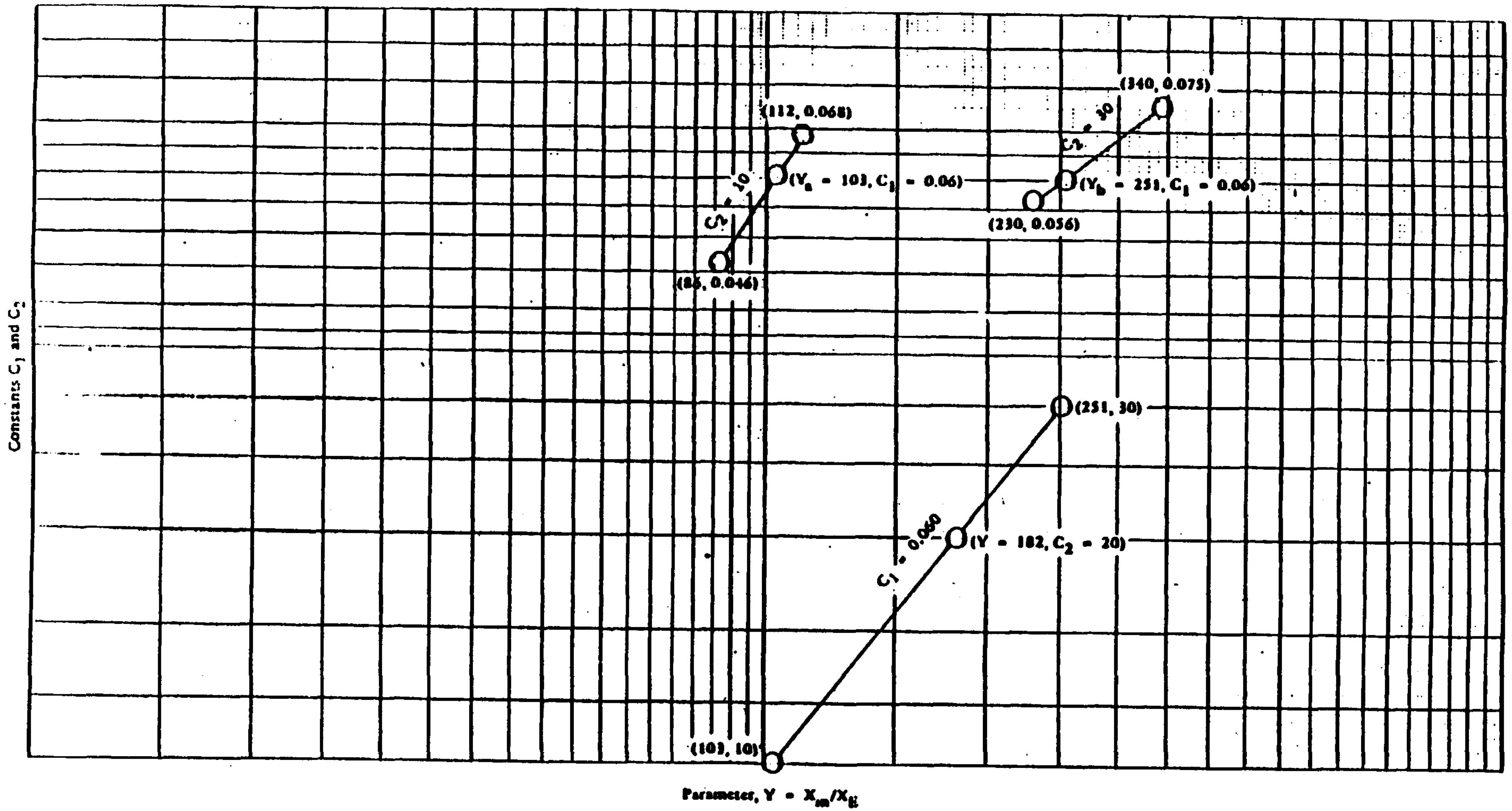
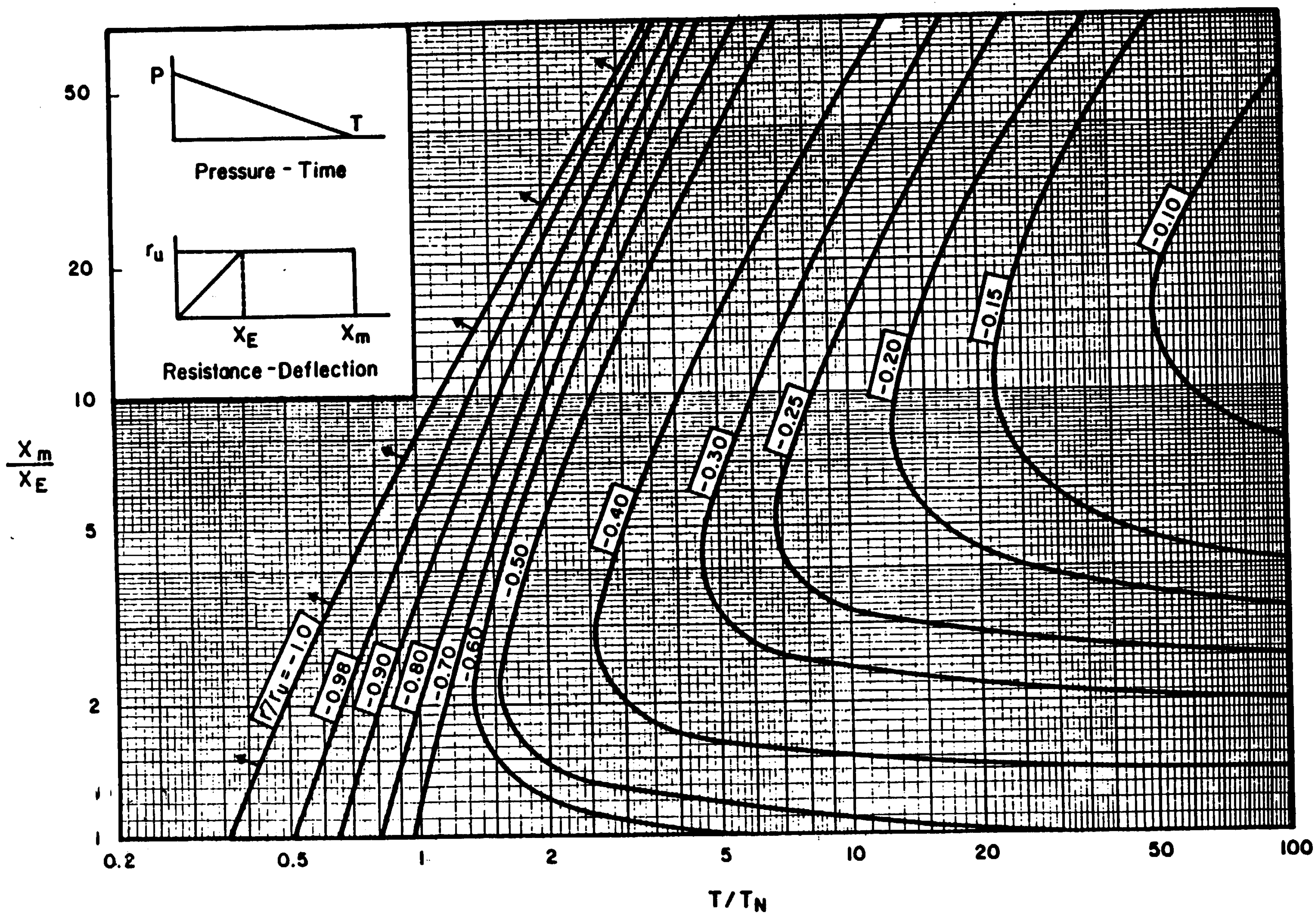


Figure 3-267 Graphical interpolation



P
T
Pressure - Time
r_u
X_E
X_m
Resistance - Deflection
$r/r_u = -1.0$
-0.98
-0.90
-0.80
-0.70
-0.60
-0.50
-0.40
-0.30
-0.25
-0.20
-0.15
-0.10
$\frac{X_m}{X_E}$
50
20
10
5
2
1
0.2
0.5
1
2
5
10
20
50
100
T/T_N

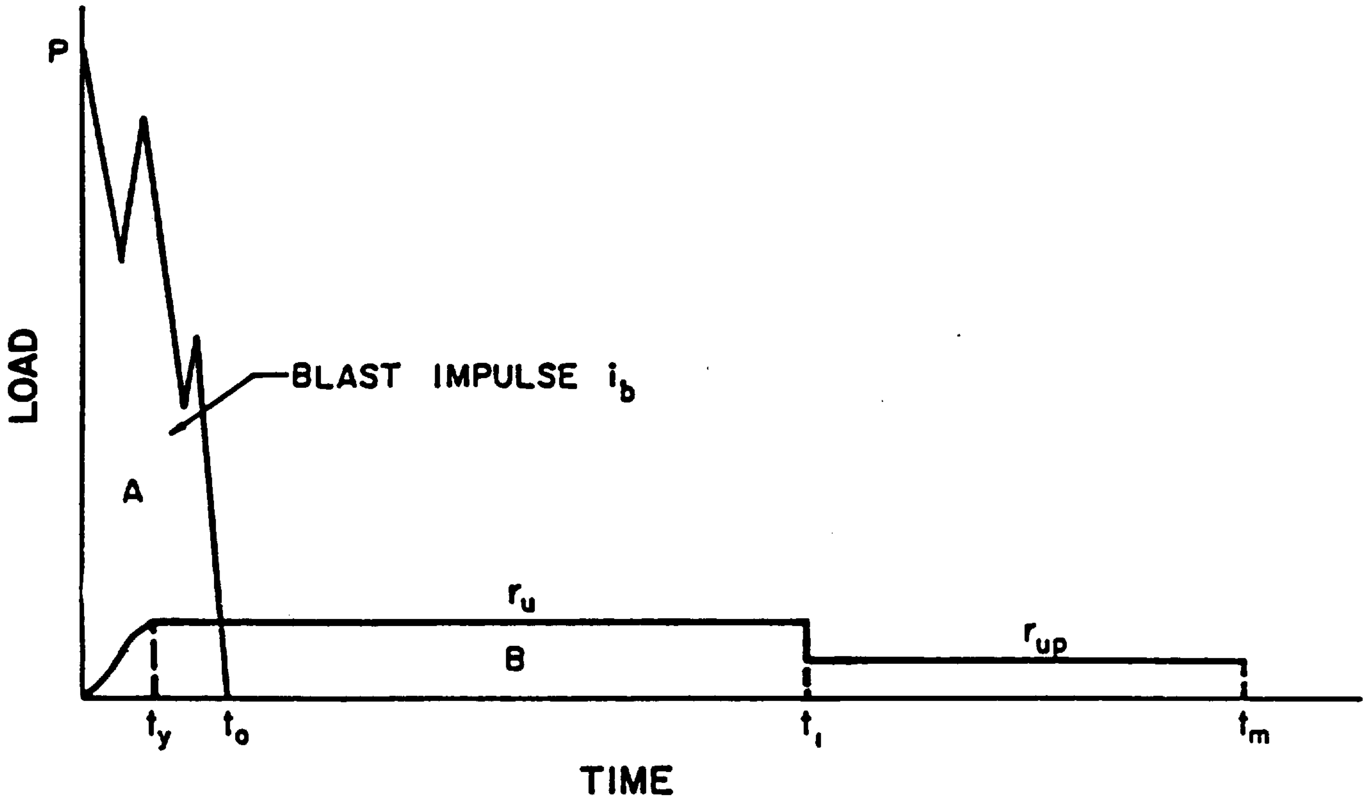


Figure 3-269 Pressure-time and resistance-time curves for elements which respond to impulse

Table 3-14 Details of computation by acceleration impulse extrapolation method

n	t	P_n	R_n	$P_n - R_n$	$a_n = (P_n - R_n)/m$	$a_n(\Delta t)^2$	$2X_n$	X_{n-1}	X_{n+1}
0	0	P_0	R_0	$P_0 - R_0$	a_0	$a_0(\Delta t_1)^2$	0	0	X_1
1	Δt_1	P_1	R_1	$P_1 - R_1$	a_1	$a_1(\Delta t_1)^2$	$2X_1$	0	X_2
2	$2(\Delta t_1)$	P_2	R_2	$P_2 - R_2$	a_2	$a_2(\Delta t_1)^2$	$2X_2$	X_1	X_3
.									
.									
j-1	$(j-1)\Delta t_1$	P_{j-1}	R_{j-1}	$P_{j-1}-R_{j-1}$	a_{j-1}	$a_{j-1}(\Delta t_1)^2$	$2X_{j-1}$	X_{j-2}	X_j
j	$j\Delta t_1$	P_j	R_j	$P_j - R_j$	a_j	$a_j(\Delta t_1)^2$	$2X_j$	X_{j-1}	X_{j+1}
j+1	$j(\Delta t_1)+\Delta t_2$	P_{j+1}	R_{j+1}	$P_{j+1}-R_{j+1}$	a_{j+1}	$a_{j+1}(\Delta t_1)^2$	$2X_{j+1}$	X_{j-1}	X_{j+2}

Table 3-15 **Figure numbers corresponding to various combinations of C_1 and C_2**

\ C2 C1 \	1.00	1.70	3.00	5.50	10.0	30.0	100.	300	1000
1.000	3-64	3-64	3-64	3-64	3-64	3-64	3-64	3-64	3-64
0.909						3-114	3-141	3-173	3-220
0.866						3-115	3-142	3-174	3-221
0.825						3-116	3-143	3-175	3-222
0.787							3-144	3-176	3-223
0.750				3-85	3-99	3-117	3-145	3-177	3-224
0.715						3-118	3-146	3-178	3-225
0.681	3-64	3-65	3-75			3-119	3-147	3-179	3-226
0.648					3-100	3-120	3-148	3-180	3-227
0.619						3-121	3-149	3-181	3-228
0.590							3-150	3-182	3-229
0.562				3-86	3-101	3-122	3-151	3-183	3-230
0.536								3-184	3-231
0.511						3-123	3-152	3-185	3-232
0.487								3-186	3-233
0.464	3-64	3-66	3-76			3-124	3-153	3-187	3-234
0.422				3-87	3-102		3-154	3-188	3-235
0.383						3-125		3-189	3-236
0.365							3-155	3-190	3-237
0.348								3-191	3-238
0.316	3-64	3-67	3-77	3-88	3-103	3-126	3-156	3-192	3-239
0.287								3-193	3-240
0.274							3-157	3-194	3-241
0.261						3-127	3-158	3-195	3-242
0.237				3-89	3-104		3-159	3-196	3-243
0.215	3-64	3-68	3-78			3-128	3-160	3-197	3-244
0.198								3-198	3-245
0.178				3-90	3-105	3-129	3-161	3-199	3-246
0.162								3-200	3-247
0.147	3-64	3-69	3-79			3-130	3-162	3-201	3-248
0.133				3-91	3-106			3-202	3-249
0.121						3-131	3-163	3-203	3-250
0.110								3-204	3-251
0.100	3-64	3-70	3-80	3-92	3-107	3-132	3-164	3-205	3-252
0.091								3-206	3-253
0.083								3-207	3-254
0.075						3-133	3-165	3-208	3-255
0.068				3-93	3-108			3-209	3-256
0.056	3-64	3-71	3-81			3-134	3-166	3-210	3-257
0.046				3-94	3-109			3-211	3-258
0.042						3-135	3-167	3-212	3-259
0.032	3-64	3-72	3-82	3-95	3-110	3-136	3-168	3-213	3-260
0.026						3-137	3-169	3-214	3-261
0.022				3-96	3-111			3-215	3-262
0.018	3-64	3-73	3-83			3-138	3-170	3-216	3-263
0.015				3-97	3-112			3-217	3-264
0.013						3-139	3-171	3-218	3-265
0.010	3-64	3-74	3-84	3-98	3-113	3-140	3-172	3-219	3-266

Table 3-16 Response Chart Interpolation

Figure Number	C_1	C_2	Desired Parameter		
1	C_{11}	C_{21}	Y_1		
	C_1	C_{21}		Y_a	
2	C_{12}	$C_{22} - C_{21}$	Y_2		
	C_1	C_2			Y
3	C_{13}	C_{23}	Y_3		
	C_1	C_{23}		Y_b	
4	C_{14}	$C_{24} - C_{23}$	Y_4		

APPENDIX 3A

ILLUSTRATIVE EXAMPLES

Problem 3A-1(A) Ultimate Unit Resistance

Problem: Determine the ultimate unit resistance of a two-way structural element using (1) general solution and (2) charts.

Procedure: Part (a) - General Solution

Step 1. Establish design parameters.

Step 2. Assume yield line locations in terms of x and/or y considering support conditions, presence of openings, etc.

Step 3. Determine negative and positive moment capacities of sections crossed by assumed yield lines.

Step 4. Establish distribution of moments across negative and assumed yield lines, considering corner effects and those of openings.

Step 5. Determine the ultimate unit resistance for each sector in terms of x and/or y considering free body diagram of the sectors (fig. 3-3). Summation of the moments about the axis of rotation (support) of the sector yields equation 3-3.

Step 6. Equate the ultimate unit resistance of the sectors and solve for the yield line location x and/or y.

Step 7. With known yield line location, solve for ultimate unit resistance of the element, using equations obtained in Step 6.

Note: For complex problems (three or more different sectors) the solution for the ultimate unit resistance is most easily accomplished through a trial-and-error procedure by determining r_u for each sector for a given (assumed) yield line location and adjusting the yield lines until the several values of r_u agree to within a few percent.

Procedure: Part (b) - Chart Solution

Step 1. Same as in step 1 of part a.

Step 2. Same as in step 2 of part a.

Step 3. Determine the negative and positive ultimate moment capacities in vertical and horizontal directions.

Step 4. For given support conditions (and value of x_2/x_1 in the case of an element with three edges supported and fourth free), use the appropriate chart (figs. 3-4 through 3-20) to obtain yield line location ratios x/L or y/H for value of quantity obtained in step 4. Then calculate x or y.

Step 5. Using the appropriate equation from table 3-2, determine the ultimate unit resistance of the element.

Example 3A-1 Ultimate Resistance

Required: Ultimate unit resistance of two-way structural steel element shown below using (1) general solution and (2) charts.

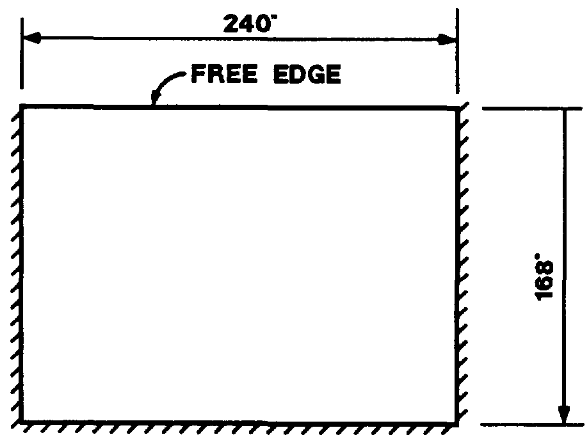


Figure 3A-1

(Solution: Part (a) - General Solution)

Step 1. Given:

(a) L = 240 in H = 168 in
(b) Fixed on three sides and free at the fourth

Step 2. Assume yield line location (fig. 3A - 2)

Step 3. The negative and positive moment capacities in both the horizontal and vertical directions are determined from the properties of the material. For this example, it will be assumed that the moment capacities are equal to M = 20,000 inlbs/in.

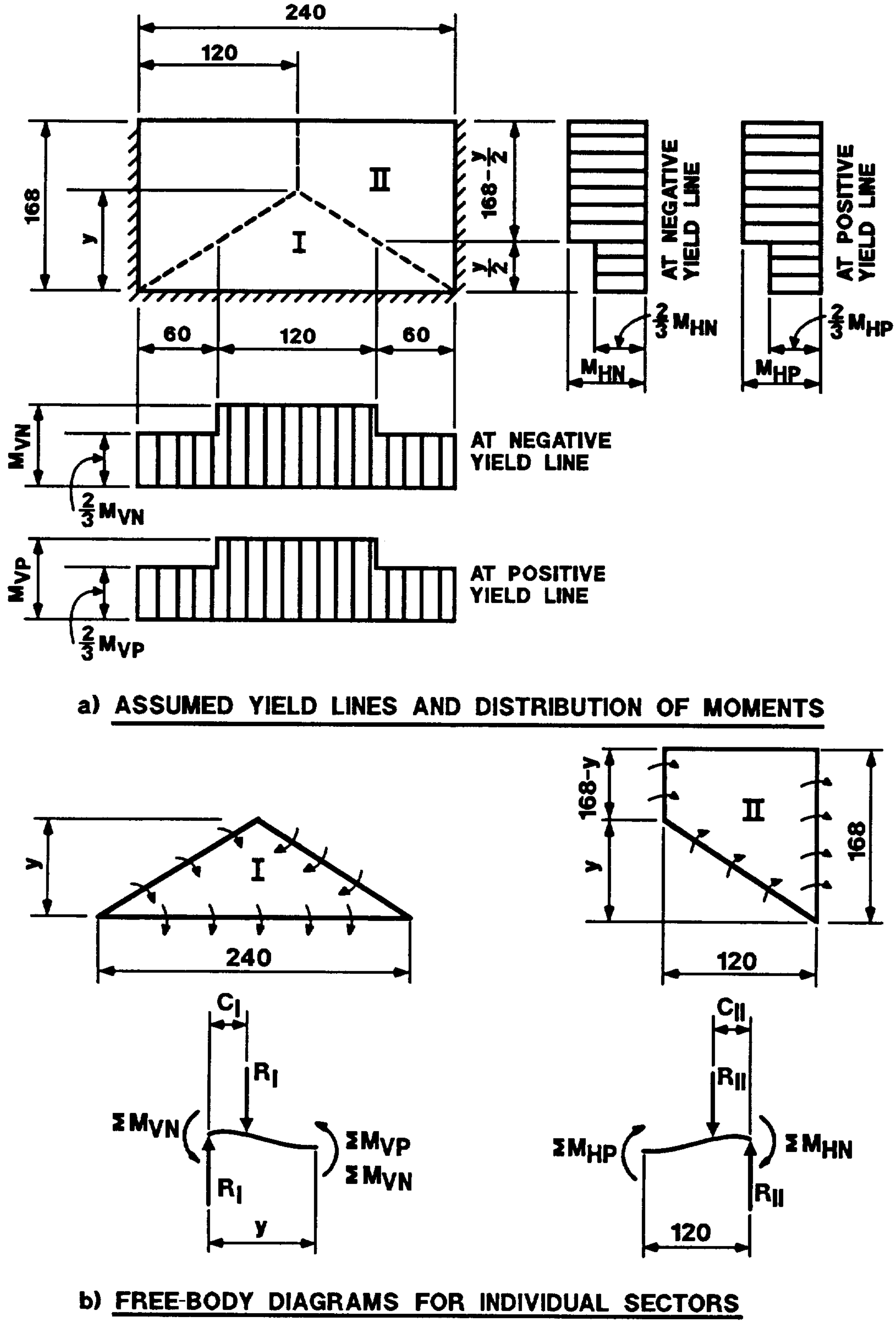

240
120
168
y
168 − y/2
y/2
I
II
60
120
60
AT NEGATIVE YIELD LINE
AT POSITIVE YIELD LINE
2/3 MHN
MHN
2/3 MHP
MHP
MVN
2/3 MVN
MVP
2/3 MVP
a) ASSUMED YIELD LINES AND DISTRIBUTION OF MOMENTS
168-y
CI
RI
ΣMVN
ΣMVP
ΣMVN
CII
RII
ΣMHP
ΣMHN
b) FREE-BODY DIAGRAMS FOR INDIVIDUAL SECTORS

Figure 3A-2

$M_{HN} = M_{HP} = M_{VN} = M_{VP} = 20{,}000$ in lbs/in.

Step 4. For distribution of moments across negative and assumed positive lines, see figure 3A - 2(a).

Step 5. The ultimate unit resistance of each sector is obtained by taking the summation of the moments about its axis of rotation (supports) so that

$$\Sigma M_N + \Sigma M_P = Rc = r_u Ac$$

a. Sector I (fig. 5A - 2)

$$\Sigma M_{VN} + \Sigma M_{VP} = 120(20{,}000) + 2(2/3)(20{,}000)(60) + 120(20{,}000) + 2(2/3)(20{,}000)(60) = 8.0\text{x}10^6 \text{ in-lbs.}$$

$$r_u Ac = r_u \left[\frac{240(y)}{2}\right] \left[\frac{y}{3}\right] = 40\ r_u y^2$$

therefore,

$$r_u = 400(20{,}000)/40y^2 = 0.2\text{x}10^6 / y^2$$

b. Sector II (fig. 3A - 2)

$$\Sigma M_{HN} + \Sigma M_{HP} = (168-y/2)(20{,}000) + 2/3(20{,}000)(y/2) + (20{,}000)(168-y/2) + 2/3(20{,}000)(y/2)$$

$$= 336(20{,}000) - y/3(20{,}000)$$

$$r_u Ac = r_u\left[\frac{120(168+168-y)}{2}\right] \left[\frac{120[168+2(168-y)}{3}\right] / (168+168-y)$$

$$= 4{,}800 r_u (252-y)$$

therefore,

$$r_u = \frac{336(20{,}000) - y/3(20{,}000)}{4800\ (252-y)}$$

Step 6. Equate the ultimate unit resistance of the sectors.

$$\frac{10(20{,}000)}{y^2} = \frac{336(20{,}000) - y/3(20{,}000)}{4800(252-y)}$$

Simplifying:

$$y^3 - 1008y^2 - 144000y + 36288000 = 0$$

and the desired root is: $y = 137.6$ ins.

Step 7. The ultimate unit resistance is obtained by substituting the value of y into either equation obtained in step 5, both of which yield:

$$r_u = (20{,}000)/(137.6)^2 = 10.6 \text{ psi}$$

Solution: Part (b) - Chart Solution

Note:
Element conforms to the requirements of section 3-8 since it is fixed on three sides and free on the remaining side and has uniform thickness in the horizontal and vertical directions.

Step 1. Same as step 1 in part a.

Step 2. For illustrative purposes, a different yield pattern (fig. 3A-3) will be assumed.

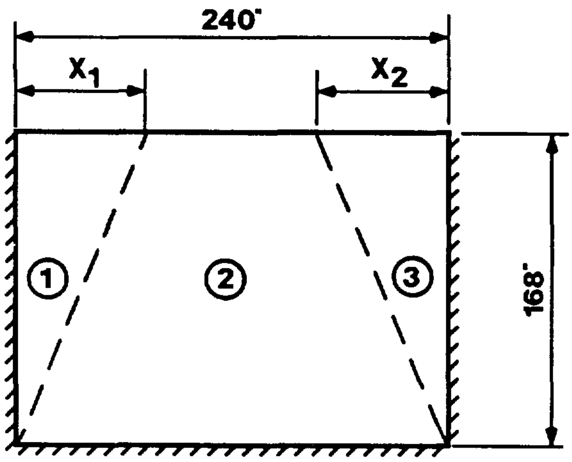


Figure 3A-3

Step 3. For ultimate moment capacities, see step 3 of part a

Step 4. For three sides fixed and the fourth free, calculate the parameter.

$$X_2/X_1=[(M_{HN3} + M_{HP})/(M_{HN1} + M_{HP})]^{1/2} = [(20{,}000)(2)/(20{,}000)(2)]^{1/2} = 1.0$$

From figure 3-11, $(X_2/X_1 = 1.0)$ calculate the parameters:

$$L/H[M_{VP}/(M_{HN1} + M_{HP})] = 240/168[20{,}000/(2)(20{,}000)]^{1/2} = 1.01$$

and

$$\frac{M_{VP}}{M_{VN2}} = \frac{20,000}{20,000} = 1.0$$

Read yield line location

X_1/L exceeds the maximum possible value of 0.5 therefore, assumed yield line pattern is wrong. Assume alternate yield line pattern as shown in figure 3A-2.

From figure 3-16 calculate the following parameters:

$$\frac{L}{H} = \frac{(M_{VN3}+ M_{VP})^{1/2}}{(M_{HN2}+ M_{HP})^{1/2} + (M_{HN1} + M_{HP})^{1/2}}$$

$$= \frac{240}{168}\left[\frac{(20,000+20,000)^{1/2}}{(20,000+20,000)^{1/2} + (20,000+20,000)^{1/2}}\right] = 0.71$$

and

$$X/L = \left[(M_{HN1}+ M_{HP}) /(M_{HN2}+ M_{HP})\right]^{1/2} /1 + \left[M_{HN1}+ M_{HP})/(M_{HN2}+ M_{HP})\right]^{1/2}$$

$$= \left[40,000/40,000\right]^{1/2} / 1 + \left[40,000/40,000\right]^{1/2} = 1/2$$

from figure 3-16 read of yield line location:

$y/H = 0.82$; $y = 0.8(168) = 137.6$ in

$X/L = 0.50$; $X = 0.5(240) = 120.0$ in

Step 5. From table 3-2

NOTE: Both equations given in the table for each edge condition and yield line location, will provide identical values of r_u.

$$r_u \frac{5(M_{VN}+ M_{VP})}{y^2} = \frac{5(20,000+20,000)}{137.6^2} = (0.00055)20,000 = 10.5 \text{ psi}$$

Example 3A-1(B) Ultimate Unit Resistance

Required: Ultimate unit resistance of the element considered in example 3A-1(A) except there is an opening as shown in figure 3A-4.

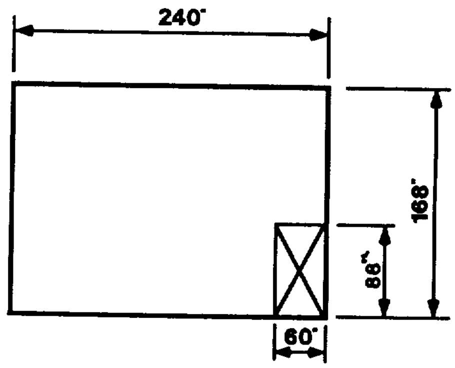


Figure 3A-4

Solution:

Step 1. Given:
(a) L = 240" H = 168" Two additional free edges are formed due to the presence of the opening.

Step 2. Assumed yield line location is shown in figrue 3A-5 (three different sectors are formed).

Step 3. Same as step 3 of Example 3A-1(A), part a.

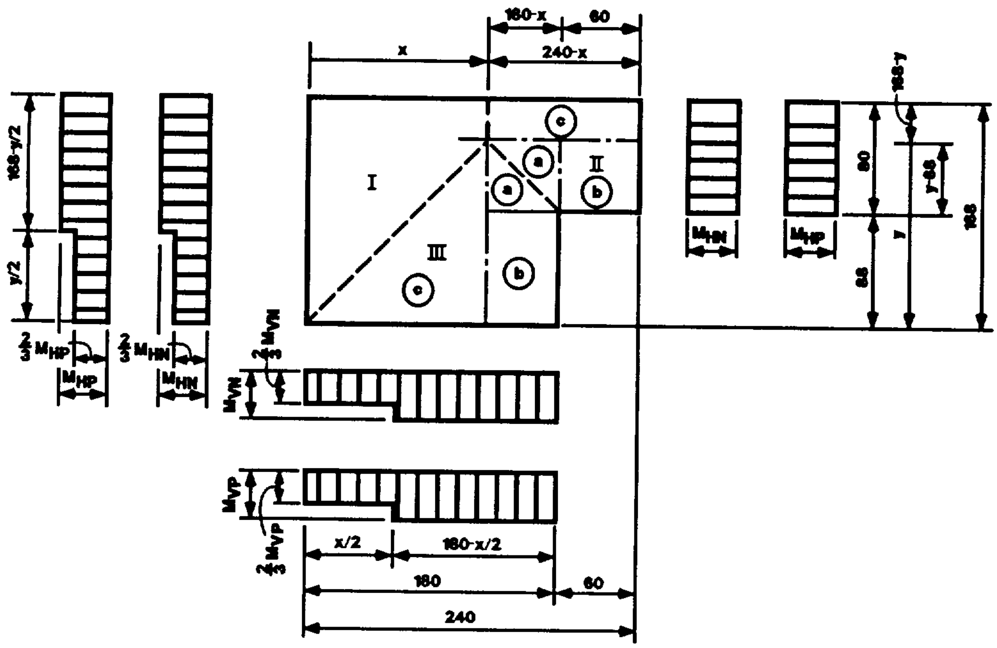


Figure 3A-5

Step 4. For distribution of moments across negative and assumed positively yield lines see figure 3A-5. (Since opening is located at lower right corner, there is no reduced moment capacity in this area.)

Step 5. The ultimate unit resistance is obtained from:

$$\Sigma M_N + \Sigma M_p = Rc = r_u Ac$$

a. Sector 1 (fig. 3A-5)

$$\begin{aligned}\Sigma M_{HN} + \Sigma M_{HP} &= (20,000)(168-y/2) + 2/3(20,000)(y/2) + \\ &\quad (20,000)(168-y/2) + 2/3(20,000)(y/2) \\ &= 336(20,000) - y/3(20,000) \\ &= (336-y/3)(20,000)\end{aligned}$$

$$\begin{aligned}r_u Ac &= r_u[x(168+168-y)/2]\ [x(168+2(168-y))/3(168+168-y)] \\ &= r_u x^2(252-y)/3\end{aligned}$$

therefore,

$$r_u = \frac{(1008-y)(20,000)}{x^2(252-y)}$$

b. Sector II (fig. 5A-5)

$$\Sigma M_{HN} + \Sigma M_{HP} = (20,000)(80) + (20,000)(80)$$

$$= 160(20,000)$$

Note:

The sector is divided into parts a, b, and c so that the centriod may be obtained (see table below).

Portion of Sector	Area (A')	Distance from Centroid to axis of rotation (c')	A'c'
a	$\frac{(y-88)(180-x)}{2}$	$\frac{(180-x)}{3} + 60 = \frac{360-x}{3}$	$\frac{(y-88)(180-x)(360-x)}{6}$
b	$(y-88)(60)$	$\frac{60}{2}$	$\frac{(y-88)(60)^2}{2}$
c	$(168-y)(240-x)$	$\frac{(240-x)}{2}$	$\frac{(168-y)(240-x)^2}{2}$

$$Ac = \Sigma A'c' = \frac{(y-88)(180-x)(360-x)}{6} + \frac{(y-88)(60)^2}{2} + \frac{(168-y)(240-x)^2}{2}$$

$$= 1/2 \frac{(y-88)}{3} [(180-x)(360-x) + 10800] + (168-y)(240-x)^2$$

$$r_u = \frac{(\Sigma M_{HN} + \Sigma M_{HP})}{Ac}$$

$$= \frac{6,400,000}{\frac{(y-88)}{3} [(180-x)(360-x) + 10,800] + (168-y)(240-x)^2}$$

c. Sector III (fig. 3A-5)

$$\Sigma M_{vn} + \Sigma M_{vp} = (20,000)(180-x/2) + 2/3(20,000)(x/2) + (20,000)(180-x/2) + 2/3(20,000)(x/2)$$
$$= 360(20,000) - (20,000)x/3$$

Portion of Sector	Area (A')	Distance from Centroid to axis of rotation (c')	A'c'
a	$\frac{(108-x)(y-88)}{2}$	$\frac{(y-88)}{3} + 88 = \frac{y + 176}{3}$	$\frac{(180-x)(y-88)(y+176)}{6}$
b	$(180-x)(88)$	$\frac{88}{2}$	$\frac{(180-x)(88)^2}{2}$
c	$\frac{xy}{2}$	$\frac{y}{3}$	$\frac{xy^2}{6}$

$$Ac = \Sigma A'c' = (y-88)(180-x)(y+176)/6 + (180-x)(88)^2/2 + xy^2/6$$
$$= 1/6 \ (180-x)[(y-88)(y+176)+23,232] + xy^2$$

$$r_u = \frac{\Sigma M_{HN} + \Sigma M_{HP}}{Ac}$$

$$= \frac{(2160-2x)(20,000)}{(180-x)[(y-88)(y+176)+23,232]+xy^2}$$

Step 6. Due to the complexity of obtaining a direct solution for ultimate unit resistance, a trial-and-error solution will be used (see table below):

x	y	r_I	r_{II}	r_{III}
125	130	9.21	7.67	9.33
125	135	9.55	7.92	8.77
125	140	9.92	8.19	8.25
125	145	10.32	8.48	7.78
125	150	10.77	8.79	7.35
130	130	8.52	8.29	9.50
130	135	8.83	8.55	8.92
131	135	8.70	8.68	8.85

Therefore:

$x = 131$ ins
$y = 135$ ins
$r_u = 8.68$ psi

Problem 3A-2 Resistance - Deflection Function

Problem: Determine the actual and equivalent resistance deflection function in the elasto-plastic region for a two-way structural element.

Procedure:

Step 1. Establish design parameters
a. Geometry of element.
b. Support conditions

Step 2. Determine ultimate positive and negative moment capacities.

Step 3. Determine static properties:
a. Modules of elasticity for the element.
b. Moment of inertia of the element.

Step 4. Establish points of interest and their ultimate moment capacities (fig. 3-23)

Step 5. Compute properties at first yield.
a. Location of first yield
b. Resistance at first yield r_e
c. Moments at remaining points consistent with r_e
d. Maximum deflection at first yield.

Step 6. Compute properties at second yield
a. Remaining moment capacity at other points
b. Location of second yield.
c. Change in unit resistance Δr between first and second yield.
d. Unit resistance at second yield r_{ep}.
e. Moment at remaining point consistent with r_{ep}.

f. Change in maximum deflection.
g. Total maximum deflection.

Note:

An element with unsymmetrical support conditions may exhibit three or four support yields. Therefore, repeat Step 6 as many times as necessary to obtain properties at the various yield points.

Step 7. Compute properties at final yield (ultimate unit resistance)

a. Ultimate unit resistance.
b. Change in resistance between ultimate unit resistance and resistance at prior yield.
c. Change in maximum deflection (for elements supported on two, three, or four sides, use stiffness obtained from figure 3-26, 3-30 and 3-36, respectively).
d. Total maximum deflection.

Step 8. Draw the actual resistance-deflection curve (fig. 3-39).

Step 9. Calculate equivalent maximum elastic deflection of the element.

Example: 3A-2 Resistance-Deflection Function

Required: The actual and equivalent resistance-deflection function (curve) in the elasto-plastic region for the two-way structural steel element.

Solution:

Step 1. Given:

a. L = 240 in. H = 168 in.
b. Fixed on three sides and free at the fourth.

Step 2. Same as step 3 of example 3A-1(A), part a.

Step 3. Static properties.

a. Modulus of elasticity, E_s for steel

$E_s = 29 \times 10^6$ psi

b. Considering a 1-inch strip (b = 1 inch)

Assume I = 144 in^4

Step 4. For points of interest, see figure 3A-6.

Step 5. Properties at first yield.

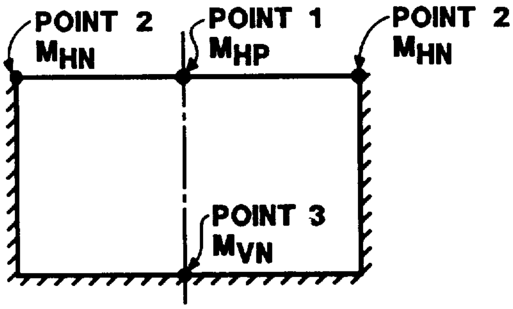


Figure 3A-6

From figure 3-27 for H/L = 0.7

$\beta_1 = 0.077$ $\beta_2 = 0.160$ $\beta_3 = 0.115$

$\gamma_1 = 0.012$ $\nu = 0.3$

a. $M_{HP} = M_{HN} = M_{VP} = M_{VN} = 20{,}000$ in-lbs/in

$M_P = \beta r H^2$

$r = M/\beta H^2$

$r_1 = 20{,}000/[(0.077)(168)^2] = 9.20$ psi

$r_2 = 20{,}000/[(0.160)(168)^2] = 4.43$ psi

$r_3 = 20{,}000/[(0.115)(168)^2] = 6.16$ psi

First yield at point 2 (smallest r)

b. $r_e = 4.43$ psi

c. M_P (Point 1) $= (0.077)(4.43)(168)^2 = 9{,}627$ in-lbs/in

M_N (Point 3) $= (0.115)(4.43)(168)^2 = 14{,}379$ in-lbs/in

d. $D = EI/b(1-\nu^2)$

$= 29 \times 10^6 \times 144/1[1-(0.3)^2] = 45.9 \times 10^8$ in-lbs

$X_e = \gamma_1 r_e H^4/D = (0.0120)(4.43)(168)^4 / 43(10^8) = 0.0092$ in

Step 6. Properties at second yield.

After first yield element assumes a simple-simple-fixed-free stiffness, therefore from figure 3-29 for H/L = 0.7.

β_1 = 0.120 β_3 = 0.220

γ_1 = 0.045 ν = 0.3

a. M_P (Point 1) = M_{HP} - M_P (at r_e)

= 20,000 - 9627 = 10373 in-lbs/in

M_N (Point 3) = M_{VN} - M_P (at r_e)

= 20,000 - 14,379 = 5621 in-lbs/in

b. M_P (Point 1) = 10373 in-lbs/in = $\beta_1 \Delta r H^2$

Δr = $10373/(0.120)(168)^2$ = 3.06 psi

M_n (Point 3) = 5,621 in-lbs/in = $\beta_3 \Delta r H^2$

Δr = $5,621/[(0.220)(168)^2]$ = 0.90 psi

Second yield at Point 3 (smaller Δr)

c. Δr = 0.90 psi

d. $r_{ep} = r_e + \Delta r$ = 4.43 + 0.90 = 5.33 psi

e. M_P (Point 1) = $0.120(0.90)(168)^2$

= 3.048 in-lbs/in

f. $D = EI/b(1-\nu^2) = (29)(10^6)(144)/1[1-(0.3)^2]$

= 45.9×10^8 in-lbs/in

$\Delta x = \gamma_1 \Delta r H^4/D = 0.030(0.90)(168)^4/45.9(10)^8$

= 0.0047 in

g. $X_{ep} = X_e + \Delta X$ = 0.0092 + 0.0047 = 0.014 in

Step 7. Properties at final yield (ultimate unit resistance). After second yield element assumes a simple-simple-simple-free stiffness, therefore from figure 3-30 for H/L = 0.7.

γ_1 = 0.045 ν = 0.3

a. r_u = 10.6 psi (part a, example 3A-1(A))

b. $\Delta r = r_u - r_{ep}$ = 10.6 - 5.33 = 5.27 psi

c. $D = EI/b(1-v^2) = 29(10^6)(144)/1[1-(0.3)^2]$

$= 45.9 \times 10^8$ in-lbs

$\Delta x = \gamma_1 r H^4 / D = (0.045)(5.27)(168)^4/45.9 \times 10^8$

$= 0.041$ in

d. $X_p = X_{ep} + \Delta X = 0.014 + 0.041 = 0.055$ in

Step 8. For actual resistance-deflection curve, see figure 3A-7.

Step 9. $X_E = X_e(r_{ep}/r_u) + X_{ep}[1-(r_e/r_u)] + X_p[1-(r_{ep}/r_u)]$ Equation 3-35

$X_E = 0.0092(5.33/10.6) + 0.014\ [1-(4.43/10.6)]$

$+ 0.055[1-(5.33/10.6)]$

$= 0.00463 + 0.0081 + 0.0273$

$= 0.040$ in

The equivalent resistance-deflection curve is shown in figure 3A-7.

Problem 3A-3 Dynamic Design Factors For A One Way Element

Problem: Determine the plastic load, mass and load-mass factors for a one-way element.

Procedure:

Step 1. Establish design parameters.

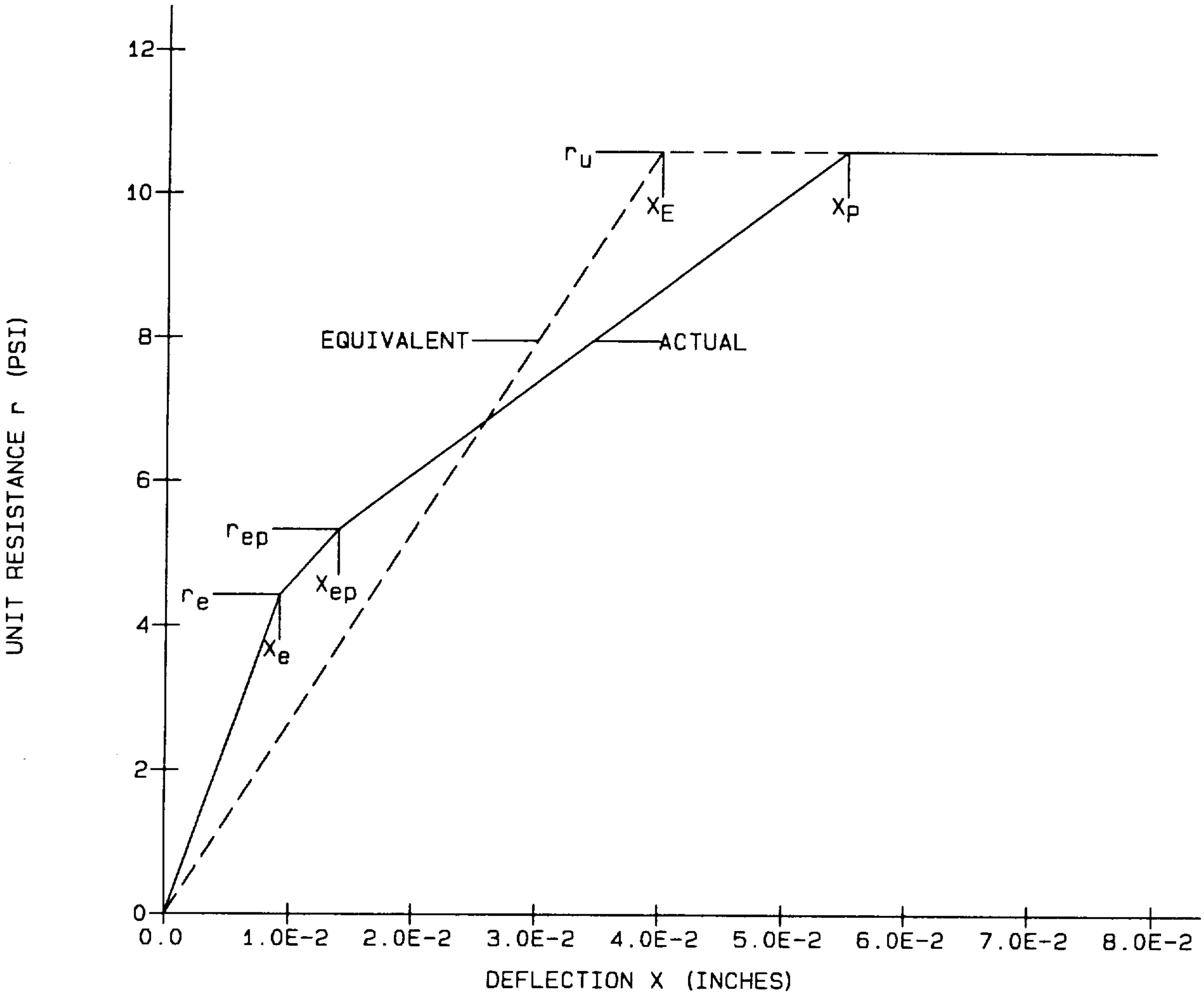
Step 2. Determine deflected shape.

a. geometry of element
b. support conditions
c. type of load and mass

Step 3. Determine maximum deflection

Step 4. Determine deflection function

a. For distributed load and/or continuous mass determine the deflection at any point.



12
10
8
6
4
2
0
UNIT RESISTANCE r (PSI)
r u
X E
X P
EQUIVALENT
ACTUAL
r ep
X ep
r e
X e
0.0
1.0E-2
2.0E-2
3.0E-2
4.0E-2
5.0E-2
6.0E-2
7.0E-2
8.0E-2
DEFLECTION X (INCHES)

Figure 3A-7

b. For concentrated loads and concentrated mass determine the deflection at the load.

Step 5. Calculate the shape function

a. For distributed load and/or continuous mass calculate $\phi(x)$, equation 3-43.

b. For concentrated load and concentrated mass calculate ϕ_r, equation 3-46.

Step 6. Calculate the load factor, K_L.

a. Use equations 3-41 and 3-42 for a distributed load.

b. Use equations 3-41 and 3-45 for a concentrated load

Step 7. Calculate the mass factor, K_M.

a. Use equations 3-47 and 3-48 for a continuous mass

b. Use equations 3-44 and 3-49 for concentrated mass

Step 8. Calculate the load-mass factor K_{LM}, from equation 3-53.

Example 3A-3(A) Dynamic Design Factors For A One-Way Element

Required: The load, mass and load-mass factors for a structural steel beam in the elastic range, with a distributed load.

Solution:

Step 1: Given structural steel beam shown in figure 3A-8

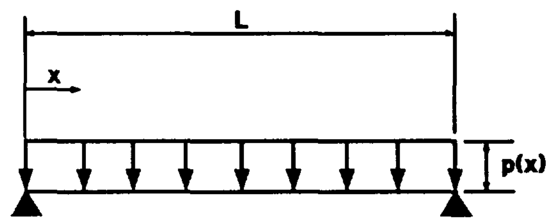


Figure 3A-8

a. L = 120 in.
b. Simply supported on both edges
c. $p(x) = 2{,}000$ lb/in
$m(x) = 0.0055(lb\text{-}s^2/in^4)/in$

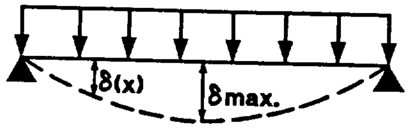


Figure 3A-9

Step 2: Assumed deflected shape for elastic range is shown in figure 3A-9

Step 3: The maximum deflection at the center is

$$\delta_{max} = \frac{5p(x)L^4}{384\ EI}$$

Step 4: Determine deflection function

$$\delta(x) = \frac{p(x)}{24EI}\ (L^3 - 2Lx^2 + x^3)$$

Step 5: Calculate the shape function using equation 3-43

$$\phi = \frac{\delta(x)}{\delta_{max}} = \frac{p(x)x}{24EI}\ (L^3 - 2Lx^2 + x^3)\ \frac{384EI}{5p(x)L^4}$$

$$= \frac{16}{5L^4}\ (L^3x - 2Lx^3 + x^4)$$

Step 6: a. Using equation 3-42, determine equivalent force

$$F_E = \int_0^L p(x)\phi(x)dx = \int_0^{120} (2{,}000\ \text{lb/in})\ \frac{16}{5L^4}\ (L^3x - 2Lx^3 + x^4)dx$$

$$= \frac{6{,}400}{L^4}\left[\frac{L^3x^2}{2} - \frac{2Lx^4}{4} + \frac{x^5}{5}\right]_0^{120} = 1{,}280L$$

$= 153{,}600$ lb.

b. From equation 3-41, find the load factor

$$K_L = \frac{F_E}{F} = \frac{153{,}600\ \text{lb.}}{(2{,}000\ \text{lb/in} \times 120\ \text{in.})}$$

$K_L = 0.64$ in the elastic range

Step 7: a. Find the equivalent mass from equation 3-48

$$M_E = \int_0^L m(x)\phi(x)^2 dx = .0055 \frac{256}{25L^8} \int_0^{120} (L^3x - 2Lx^3 + x^4)^2 \; dx$$

$$= \frac{1.408}{25L^8} \int_0^{120} (L^6x^2 - 4L^4x^4 + 2L^3x^5 + 4L^2x^6 - 4Lx^7 + x^8)dx$$

$$= \frac{1.408}{25L^8} \left[\frac{L^6x^3}{3} - \frac{4L^4x^5}{5} + \frac{2L^3x^6}{6} + \frac{4L^2x^7}{7} - \frac{4Lx^8}{8} + \frac{x^9}{9} \right]_0^{120}$$

$$= .00277L$$

$$= 0.3325 \text{ lb}^2\text{- s}^3\text{/in}$$

b. From equation 3-47, calculate the mass factor

$$K_M = \frac{M_E}{M} = \frac{0.3325 \text{ lb - s}^2 \text{ /in}^3}{(0.0055 \text{ lb - s}^2 \text{ /in}^4 \text{ x } 120 \text{ in})}$$

K_M = 0.50 in the elastic range

Step 8: Calculate the load-mass factor as defined by equation 3-51

$$K_{LM} = K_M/K_L$$

$$= 0.50/0.64$$

K_{LM} = 0.78 in the elastic range

Example 3A-3(B) Dynamic Design Factors For A One-Way Element

Required: The load, mass and load-mass factors for a structural steel beam in the plastic range with a distributed load.

Solution:

Step 1. Given the structural steel beam shown in figure 3A-8

a. L = 120 in.
b. Simply-supported on both ends
c. p(x) = 2,000 lb/in
d. m(x) = 0.0055 (lb - s^2/in^4)/in

Step 2. Assume deflected shape for the plastic range is shown in figure 3A-10

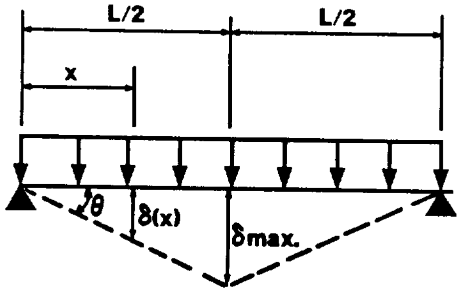


Figure 3A-10

Step 3. Determine maximum deflection

$$\delta_{max} = (L/2)\tan\theta$$

Step 4. Determine the deflection at any point.

$$\delta(x) = x\tan\theta \qquad x < L/2$$

Step 5. Calculate the shape function, equation 3-43

$$\phi(x) = \frac{\delta(x)}{\delta_{max}} = \frac{x\tan\theta}{(L/2)\tan\theta}$$

$$= 2x/L \quad x < L/2$$

Step 6:

a. Find F_E using equation 3-42.

$$F_E = \int_0^L p(x)\phi(x)dx = 2\int_0^{60} 2{,}000 \text{ lb/in})(2x/L)dx$$

$$= 4{,}000 \text{ lb/in} \left[x^2 /L \right]_0^{60}$$

$$= 120{,}000 \text{ lb}$$

b. From equation 3-41

$$K_L = \frac{F_E}{F} = \frac{120{,}000 \text{ lb.}}{(2{,}000 \text{ lb/in})\ 120 \text{ in}}$$

$K_L = 0.5$ in the plastic range

Step 7:

a. Use equation 3-48 to find the equivalent mass

$$M_E = \int_0^L m(x)\phi^2(x)dx = 2\int_0^{60} (0.0055)(4\ x^2/L^2)dx$$

$$= 0.044 \left[\frac{x^3}{3L^2} \right]_0^{60}$$

$$= 0.22 \text{ lb - s}^2/\text{in}^3$$

b. As defined by equation 3-47

$$K_M = \frac{M_E}{M} = \frac{0.22 \text{ lb - s}^2 \text{/in}^3}{(0.0055 \text{ lb - s}^2 \text{/in}^4)120 \text{ in}}$$

$K_M = 0.33$ in the plastic range

Step 8. Calculate K_{LM} using equation 3-53

$$K_{LM} = K_M/K_L$$

$$= 0.33/0.5$$

$K_{LM} = 0.66$ in the plastic range

Example 3A-3(C) Dynamic Design Factors For A One-Way Element

Required: The load, mass and load-mass factors for a structural steel beam in the elastic range, with a concentrated load.

Solution:

Step 1: Given structural steel beam shown in figure 3A-11

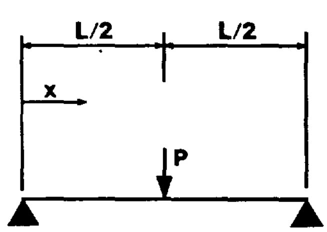


Figure 3A-11

a. L = 120 in.
b. Simply supported on both sides
c. F = 240 kips

$m(x) = 0.0055(\text{lb - s}^2/\text{in}^4)/\text{in.}$

Step 2: Assume deflected shape for elastic range is shown in figure 3A-12

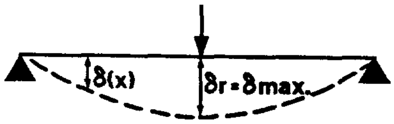


Figure 3A-12

Step 3: Determine maximum deflection

$$\delta_{max} = \frac{PL^3}{48EI}$$

Step 4: Determine deflection functions

a. for continuous mass,

$$\delta(x) = \frac{Px}{48EI}(3L^2 - 4x^2)$$

b. for concentrated load

$$\delta_r = \frac{PL^3}{48EI}$$

Step 5: Calculate shape functions

a. for continuous mass use equation 3-43

$$\phi(x) = \frac{\delta(x)}{\delta_{max}} = \frac{Px(3L^3 - 4x^2)}{48EI} \quad \frac{48EI}{PL^3}$$

$$= (3L^2x - 4x^3)/L^3$$

b. for concentrated load, use equation 3-46

$$\phi_r = \frac{PL^3}{48EI} \quad \frac{48EI}{PL^3}$$

$$= 1.0$$

Step 6:

a. Find equivalent force from equation 3-45

$$F_E = \sum^{i} F_r\phi_r = Px1 = 240 \text{ kips}$$

b. Using equation 3-41, calculate the load factor

$$K_L = \frac{F_E}{F} = \frac{240 \text{ kips}}{240 \text{ kips}}$$

$K_L = 1.0$ for the elastic range

Step 7: a. Equation 3-48 gives the equivalent mass.

$$M_E = \int_0^L m(x)\phi^2(x)\, dx = \int_0^{120} \frac{(0.0055)}{L^6} (9L^4x^2 - 24L^2x^4 + 16x^6)dx$$

$$= \frac{0.0055}{L^6}\left[3L^4 x^3 - \frac{24L^2 x^5}{5} + \frac{16x^7}{7}\right]_0^{120}$$

$$= 0.0027L$$

$$= 0.32 \text{lb} - s^2/in^3$$

b. From equation 3-47, calculate the mass factor

$$K_M = \frac{M_E}{M} = \frac{0.32 \text{lb} - s^2/in^3}{(0.0055 \text{lb} - s^2/in^4 \times 120in)}$$

$K_M = 0.49$ in the elastic range

Step 8: Calculate the load-mass factor, from equation 3-53

$$K_{LM} = K_M/K_L$$

$$= 0.49/1.0$$

$K_{LM} = 0.49$ for the elastic range

Example 3A-3(D) Dynamic Design Factors For A One-Way Element

Required: Determine the load, mass and the load-mass factors for a structural steel beam, in the plastic range, with a concentrated load.

Solution:

Step 1. Given structural steel beams shown in figure 3A-11.

a. L = 120 in

b. Simply-supported at both edges

c. F = 240 kips

$m(x) = 0.0055\ (lb - s^2/in^4)/in$

Step 2. Assumed deflected shape for the plastic range is shown in figure 3A-13

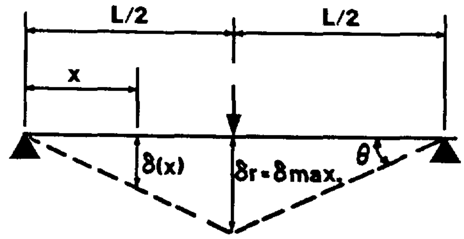


Figure 3A-13

Step 3: Determine maximum deflection

$\delta_{max} = (L/2)\tan\Theta$

Step 4: Determine deflection function.

a. for continuous mass

$\delta(x) = x\tan\Theta \qquad x < L/2$

b. for a concentrated load

$\delta_r = (L/2)\tan\Theta$

Step 5: Calculate shape factors using

a. equation 3-43 for continuous mass

$$\phi(x) = \frac{\delta(x)}{\delta_{max}} = \frac{x\tan\Theta}{(L/2)\tan\phi}$$

$$= 2x/L \qquad x < L/2$$

b. equation 3-46 for concentrated load

$$\phi_r = \frac{\delta_r}{\delta_{max}} = \frac{(L/2)\tan\Theta}{(L/2)\tan\Theta}$$

$$= 1.0$$

Step 6: a. The equivalent force is found using equation 3-45

$$F_E = \sum_{r=1}^{i} F_r\phi_r = Px_1 = 240 \text{ kips}$$

b. Equation 3-41 gives the load factor

$$K_L = \frac{F_E}{F} = \frac{240 \text{ kips}}{240 \text{ kips}}$$

K_L = 1.0 for plastic range

Step 7: a. The equivalent mass is found using equation 3-48

$$M_E = \int_0^L m(x)\phi^2(x)dx = 2\int_0^{60} (0.0055)(4\ x^2/L^2)dx$$

$$= 0.044 \left[\frac{x^3}{3L^2} \right]_0^{60} = 0.22 \text{ lb - s}^2/\text{in}^3$$

b. Solve for K_M using equation 3-47

$$K_M = \frac{M_E}{M} = \frac{0.22 \text{ lb - s}^2/\text{in}^3}{(0.0055 \text{ lb - s}^2/\text{in}^4)120 \text{ in}}$$

K_M = 0.33 in the plastic range

Step 8: From equation 3-53, calculate K_{LM}

$K_{LM} = K_M/K_L$

= 0.33 in the plastic range

Problem 3A-4 Plastic Load-Mass Factor

Problem: Determine the plastic load-mass factor K_{LM} for a two-way element using (1) general solution and (2) chart solution.

Note: The determination of the plastic load-mass factor follows the calculations for the ultimate resistance, hence the structural configuration and the location of the plastic yield lines will be known.

Procedure: Part (a) - **General Solution**

Step 1. See part a, problem 3A-1 for the structural configuration and location of plastic yield lines. Denote sectors formed by yield lines.

Step 2. Determine the load-mass factors properties I, c, and L' for all sectors.

Step 3. Determine the factor I/cL' for all sectors.

Step 4. Calculate the total area of the element.

Step 5. With values obtained above, calculate the plastic load-mass factor for the element using equation 3-57.

Note: In the above problem, an element of uniform thickness was considered. For non-uniform elements, the load-mass factor is calculated using equation 3-53 where the mass of the individual sectors must be considered.

Procedure: Part (b) - **Chart Solution**

Step 1. See part b, problem 3A-1 for structural configuration and location of plastic yield lines in terms of x/L or y/H.

Step 2. For known value of X/L or y/H and support condition, determine the load-mass factor for the element from figure 3-44.

Note: Chart solution may be used only if the element conforms to the requirements listed in section 3-17.3

Example 3A-4 Plastic Load-Mass Factor

Required: Plastic load-mass factor for the element considered in example 3A-1(A) using (1) general solution and (2) chart solution.

Solution: Part (a) - **General Solution**

Step 1. Given structural configuration and location of yield lines shown below (see part a, example 3A-1(A)) in figure 3A-14.

$L = 240$ in
$H = 168$ in
$X = 120$ in
$y = 137.6$ in
T_c = constant

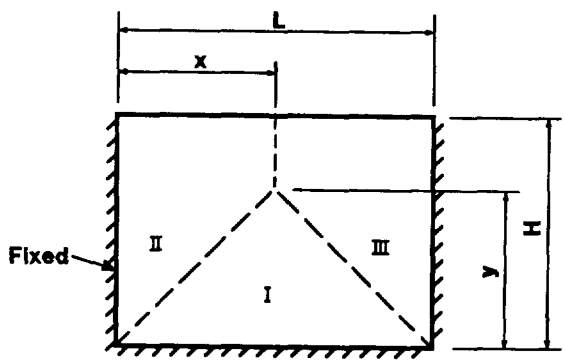


Figure 3A-14

Step 2. Load-mass factor properties.

a. Sector 1.

$L' = y = 137.6$ in
$c = y/3 = 137.6/3$
$I = L(L'^3)/12 = 240(137.6)^3/12.$

b. Sector II.

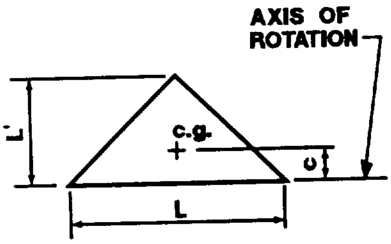


Figure 3A-15

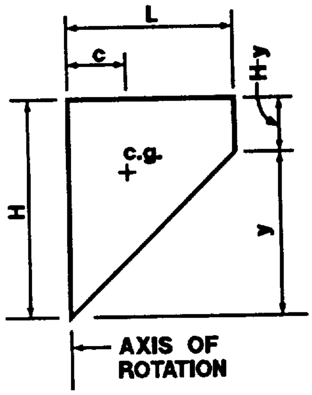


Figure 3A-16

$L' = x = 120$ in
$H - y = 168 - 137.6 = 30.4$ in

$$c = \frac{L' [H + 2 (H-y)]}{3 [H + (H-y)]} = \frac{120 [168 + 2 (30.4)]}{3 (168 + 30.4)}$$

$$c = 120 (0.384)$$

$$I = \frac{(H-y)(L')^3}{3} + \frac{y(L')^3}{12}$$

$$= \frac{30.4 (120)^3}{3} + \frac{137.6(120)^3}{12} = 21.60(120)^3$$

Step 3. Calculate factor I/cL' for each sector:

Sector I. $$\frac{I}{cL'} = \frac{240(137.6)^3 / 12}{(133.4/3)(133.4)} = 8{,}256 \text{ in}^2$$

Sector II. $$\frac{I}{cL'} = \frac{21.60(120)^3}{(0.390 \times 120)(120)} = 6{,}646 \text{ in}^2$$

Sector III. $$\frac{I}{cL'} = 6{,}646 \text{ in}^2$$

Step 4. Area of panel
$A = LH = 240 (168) = 40{,}320 \text{ in}^2$

Step 5. Load-mass factor

$$K_{LM} = \frac{I/cL'}{A} \qquad \text{(eq. 6-14)}$$

$$K_{LM} = \frac{8,256 + 2(6,646)}{40,320} = 0.534$$

Solution: Part (b) - **Chart Solution**

Step 1. Given: Panel fixed on 3 edges, 1 free and y/H = 0.803 (see part b, example 3A-1(A)).

Step 2. From figure 3-44, read load-mass factor

$K_{LM} = 0.543$

Problem 3A-5 Response of a Single-Degree-of Freedom System subject to Dynamic Load

Problem: Determine the maximum response and the corresponding time it occurs of a single-degree-of-freedom system subjected to dynamic load using (a) numerical methods and (b) design charts.

Procedure: Part (a) - **Numerical Methods**

Step 1. Establish dimensional parameters of the system.

Step 2. Determine the natural period of vibration and integration time interval.

Step 3. Construct a table similar to table 3-14 of section 3-19.2. Note:For the first interval n=1, Equation 3-59 is used and subsequent intervals, the recurrence formula (eqn. 3-56) is used.

Procedure: Part (b) - **Chart solution**

Step 1. Same as step 1 of example 3A-5, part a.

Step 2. Determine the non-dimensional parameters.

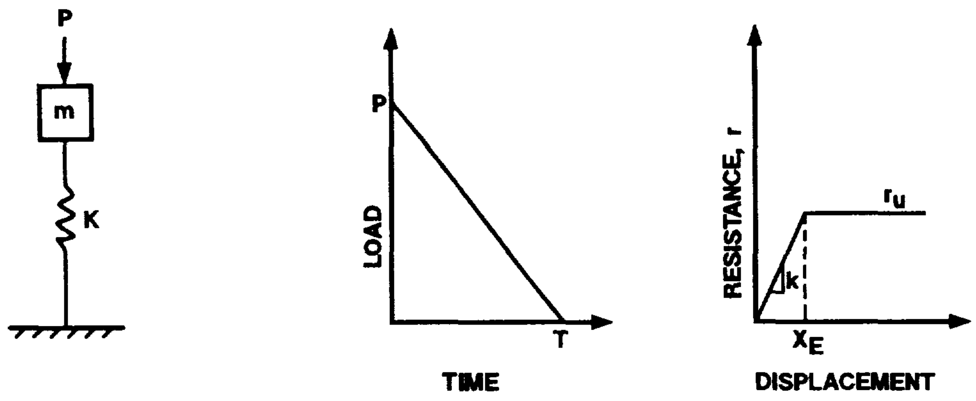
Step 3. Determine.the ratio of the maximum displacement to the elastic displacement X_m/X_E and the ratio of the time at which this maximum displacement occurs to the duration of the blast load.

Example 3A-5 Maximum Response of Single-Degree-of-Freedom System Subjected to a Triangular Load.

Required: The maximum response and the time it occurs, of a single-degree-of-freedom system subjected to blast loads, using (a) numerical methods and (b) design charts.

Solution: Part (a) - Numerical Methods

Step 1. Given:



(a) Single-Degree-of-Freedom System **(b) External Load** **(c) Resistance Function**

Figure 3A-17

$m = 2.5$ Kips-sec^2/ft
$K = 9,860$ Kips/ft
$r_u = 750$ Kips
$X_E = 0.076$ ft
$T = 0.10$ sec
$P = 1000$ Kips

Step 2. Natural period of vibration and integration time interval.

$$T_N = 2\pi\ [m/K]^{1/2} = 2\pi\ [2.5/9,860]^{1/2} = 0.10 \text{ sec}$$

$$t = T_N/10 = 0.01 \text{ sec}$$

Step 3. Construct table as shown below.

1	2	3	4	5	6	7	8	9	10
n	t (sec)	P_n Kips	R_n (Kips)	P_n-R_n (Kips)	A_n=(P_n-R_n/m (ft/sec^2)	$a_n(\Delta t)^2$ (ft)	$2X_n$ (ft)	X_{n-1} (ft)	X_{n+1} (ft)
0	0	1000	0	1000	400	0.040	0.0	0.0	0.020
1	0.01	900	197.200	702.800	281.120	0.028112	0.0400	0.0	0.068112
2	0.02	800	671.684	128.426	51.366	0.05137	0.13622	0.020	0.121357
3	0.03	700	750	-50.0	-20.0	-0.00200	0.242714	0.06811	0.17261
4	0.04	600	750	-150.0	-60.0	-0.00600	0.34522	0.121357	0.21786
5	0.05	500	750	-250.0	-100.0	-0.0100	0.43673	0.17261	0.25312
6	0.06	40	750	-350.0	-140.0	-0.0140	0.050623	0.21786	0.27437
7	0.07	300	750	-450.0	-180.0	-0.0180	0.54874	0.25312	0.27762
8	0.08	200	750	-550.0	-220.0	-0.0220	0.55525	0.27437	0.25880
9	0.09								

Note: $P_n = f(t_n) = 1000\ [1-n(\Delta t/T)]$

$$R_n = \begin{cases} KX_n \text{ for } X_n < X_e \\ r_u = 750 \text{ for } X_n > X_e \end{cases}$$

$$X_{n+1} = 2X_n - X_{n-1} + a_n\ (\Delta t)^2$$

Note:

For n=0, X_{n+1} (Column 10) $= X_{0+1} = X_1 = (1/2)a_0(\Delta t)^2$

$= (1/2)(0.040)$

$= 0.02$ ft

For n=1, $2X_n$ (Column 8) $= 2X_1 = 2[(1/2)a_0(\Delta t)^2]$

$= 2(0.02) = 0.04$ ft

X_{n-1} (Column 9) $= X_0 = 0.0$

X_{n+1} (Column 10) $= X_2 = 2X_1 - X_0 + a_1(\Delta t)^2$

$= 2(0.02) - 0 + 0.02811$

$= 0.06811$ ft

For n=2, $2X_n$ (Column 8) $= 2X_2 = 2(0.06811)$

$= 0.13622$ ft.

X_{n-1} (Column 9) $= X_1 = 0.02$ ft.

X_{n+1} (Column 10) $= X_3 = 2X_2 - X_1 + a_2 (\Delta t)^2$

$= (2)(0.06811) - 0.02 + 0.005137$

$= 0.121357$ ft.

For n=3, 4,..., repeat the above procedure.

Solution: **Part (b) - Design Charts**

Step 1. Same as step 1 of example 3A-5, part a

Step 2. Non-dimensional parameters

a. Natural period of vibration, T_n

$$T_n = 2\pi[m/K]^{1/2} = 2\pi[2.5/9,860]^{1/2} = 0.10 \text{ sec}$$

b. Ratio of duration of blast load T to natural period T_N

$$T/T_N = 0.10/0.10 = 1.0$$

c. Ratio of peak resistance r_u to peak load P

$$r_u/P = 750/1000 = 0.75$$

Step 3. Using the ratios calculated in step 2 and figures 3-54 and 3-55, determine the value of X_m/X_E and t_m/T_N.

For $T/T_N = 1$ and $r_u/P = 0.75$

$X_m/X_E = 3.7$ from figure 3-54

$t_m/T = 0.77$ from figure 3-55

Step 4. Determine X_m and t_m

$$X_m/X_E = 3.7$$

$$X_m = (3.7)X_E = (3.7(r_u/K_E)$$

$$= (3.7)(750/9,860) = 0.28144 \text{ ft.}$$

$$t_m/T = 0.77$$

$$t_m = (0.77)T = 0.77(0.10) = 0.077 \text{ sec}$$

Problem 3A-6 Maximum Response of a Single-Degree-of-Freedom System to Bilinear Blast Loads

Problem: Determine X_m/X_E, t_m/T_N and t_E/T (when applicable) for a single-degree-of-freedom system subject to various bilinear blast loads.

Procedure: Part (a) - **Solution in Region D**

Step 1. Establish normalized parameters

Step 2. Enter table 3-15 with the given C parameters and determine which figures have to be used.

Step 3. Enter each of the figures determined in step 2, with the given values of the other two parameters and determine the region where the intersection points are located.

Step 4. Based on the region where the intersection points are located, enter the appropriate figure and find X_m/X_E, t_m/T_N and t_E/T.

Procedure: Part (b) - **Solution in Region C** - Graphical Interpolation.

Step 1. Same as step 1 in part a.

Step 2. Same as step 2 in part a.

Step 3. Same as step 3 in part a.

Step 4. Set up a table as shown in table 3A-1. Post each figure number and the corresponding values of C_1 and C_2, leaving a space between each line of information. Post in the spaces the appropriate values of C_1 and C_2 needed for interpolation. Enter each of the figures determined in Step 2 with the given parameters and find the values of X_m/X_E. Post these values in table 3A-1.

Step 5. Use log-log graph paper to plot the points obtained in Step 4. Post these values in table 3A-1, using linear interpolation where necessary.

Step 6. Plot on log-log graph paper the points which represent (X_m/X_E, C_2) for the given value of C. Use linear interpolation to find X_m/X_E for given value of C_2.

Procedure: Part (c) - **Solution in Region C** - Mathematical Interpolation

Step 1. Same as step 1 in part a.

Step 2. Same as step 2 in part a.

Step 3. Same as step 3 in part a.

Step 4. Same as step 4 in part b.

Step 5. Solve for $\ln Y_a$ and $\ln Y_b$ using equations 3-83 and 3-84.

Step 6. Solve for lnY using equation 3-85.

Step 7. Solve for Y using equation 3-86.

Example 3A-6 Maximum Response of a Single-Degree-of-Freedom System to Bilinear Blast Loads

Required: Determine X_m/X_E, t_m/T_N and t_E/T (when applicable) for a single-degree-of-freedom system subject to various bilinear blast loads.

Solution: **Part (a) - Solution in Region D**

Step 1. Given:

$P/r_u = 1.0$

$T/T_N = 3.0$

$C_1 = 0.66$

$C_2 = 50$

Step 2. Enter table 3-15 with C_1, = 0.66 and C_2 = 50. Note figures 3-119, 3-120, 3-147, and 3-148 apply.

Step 3. Enter each of the figures determined in step 2, with P/r_u = 1.0 and T/T_N = 3.0. Note that the intersection point is located to the right of the line of solid squares, defined as region D. In region D, the maximum dynamic response depends only on the shock load described by P/r_u and T/T_N; the gas load described by C_1P/r_u and C_2T/T_n does not influence the maximum dynamic response. Consequently, figures 3-64a and 3-64b for a single triangular load pulse apply. Enter figure 3-64a with P/r_u = 1.0 and T/T_N = 3.0 and find X_m/X_E = 3.55, t_m/T_N = 0.98, t_E/T = 0.086.

Solution: **Part (b) - Solution in Region C - Graphical Interpolation**

Step 1. Given:

$P/r_u = 32$

$T/T_N = 0.10$

$C_1 = 0.06$

$C_2 = 20$

Step 2. Enter table 3-15 with C_1 = 0.06 and C_2 = 20. Note figures 3- 108, 3-109, 3-133 and 3-134 apply.

Step 3. Enter each of these figures with $P/r_u = 32$ and $T/T_n = 0.10$. Note that the intersection point is not located in regions A, B or D. Therefore the intersection points lie in region C and interpolation between charts is required to obtain a solution.

Step 4. Set up table as shown in table 3A-1 below. Post each chart number and the corresponding values of C_1 and C_2 leaving a space between each line of information. Post in the spaces the appropriate values of C_1 and C_2 needed for interpolation. Enter figure 3-108 with $P/r_u = 32$ and $T/T_N = 0.10$ and find $X_m/X_E = 112$. Post this value in the table. Enter figure 3-109 with $P/r_u = 32$ and $T/T_N = 0.10$ and find $X_m/X_E = 86$. Post this value in the table. Repeat this process for figures 3-133 and 3-134, and post values for X_m/X_E in the table.

Step 5. Use log-log graph paper to plot the points (112,0.068) and (86,0.046) which represent (X_m/X_E, C_1) for $C_2 = 10$ as shown in figure 3-267. Use straight-line interpolation to find $X_m/X_E = 103$ for $C_1 = 0.060$. Post this value in the table. Repeat this process for $C_2 = 30$, and find $X_m/X_E = 251$ for $C_1 = 0.06$ as shown in figure 3-267.

Step 6. Plot on log-log graph paper the points (103,10) and (251,30) which represent X_m/X_E, C_2) for C_1, $= 0.060$. Use straight-line interpolation for finding $X_m/X_E = 182$ for $C_2 = 50$ as shown in figure 3-267. Thus the solution is $X_m/X_E = 182$.

Table 3A-1

Figure No.	C_1	C_2	X_m/X_E		
3-108	0.068		112		
	0.060	10	--	103	
3-109	0.046	10	86		
	0.060	20	--		182
3-133	0.075	30	340		
	0.060	30	--	251	
3-134	0.056	30	230		

Solution: Part (c) - Solution in region C - Mathematical Interpolation

Step 1. Same as step 1 of part (b).

Step 2. Same as step 2 of part (b).

Step 3. Same as step 3 of part (b).

Step 4. Same as step 4 of part (b).

Step 5. Using equation 3-83 and 3-84, find $\ln Y_a$ and $\ln Y_b$.

$$\ln Y_a = \ln Y_1 + \frac{\ln[Y_2/Y_1]\ \ln[C_1/C_{11}]}{\ln[C_{12}/C_{11}]}$$

$$= \ln 112 + \frac{\ln(86/112)\ln(0.060/0.068)}{\ln(0.046/0.068)}$$

$$\ln Y_a = 4.6339$$

$$\ln Y_b = \ln Y_3 + \frac{\ln[Y_4/Y_3]\ \ln[C_1/C_{13}]}{\ln[C_{14}/C_{13}]}$$

$$= \ln 340 + \frac{\ln(230/340)\ln(0.06/0.075)}{\ln(0.056/0.075)}$$

$$\ln Y_b = 5.5304$$

Step 6. Find $\ln Y$ from equation 3-85

$$\ln Y = \ln Y_a + \frac{(\ln Y_b - \ln Y_a)\ln(C_2/C_{21})}{\ln(C_{23}/C_{21})}$$

$$= 4.6339 + \frac{(5.5304 - 4.639)\ln(20/10)}{\ln(30/10)}$$

$$\ln Y = 5.1995$$

Step 7. Solve for Y using equation 3-86

$$Y = e^{\ln Y}$$

$$= e^{5.1995}$$

$$Y = 181$$

APPENDIX 3B

LIST OF SYMBOLS

a	(1) acceleration (in./ms^2) (2) depth of equivalent rectangular stress block (in.)
A	area (in.^{2})
A_a	area of diagonal bars at the support within a width b (in.^{2})
A_o	area of openings (ft^2)
A_s	area of tension reinforcement within a width b (in.^{2})
A'_s	area of compression reinforcement within a width b (in.^{2})
A_{sH}	area of flexural reinforcement within a width b in the horizontal direction on each face (in.^{2})*
A_{sV}	area of flexural reinforcement wlthin a width b in the vertical direction on each face (in.^{2})*
A_v	total area of stirrups or lacing reinforcement in tension within a distance, s_s or s_l and a width b_s or b_l (in.^{2}).
A_I, A_{II}	area of sector 1 and II, respectively (in.^{2})
b	(1) width of compression face of flexural member (in.) (2) width of concrete strip in which the direct shear stresses at the supports are resisted by diagonal bars (in.)
b_s	width of concrete strip in which the diagonal tension stresses are resisted by stirrups of area A_v (in.)
b_l	width of concrete strip in which the diagonal tension stresses are resisted by lacing of area A_v (in.)
B	constant defined in pargraph
c	(1) distance from the resultant applied load to the axis of rotation (in.) (2) damping coefficient
c_I, c_{II}	distance from the resultant applied load to the.axis of rotation for sectors I and II, respectively (in.)
c_s	dilatational velocity of concrete (ft/sec)
C	shear coefficient
C_{cr}	critical damping

* See note at end of symbols

C_d	shear coefficient for ultimate shear stress of one-way elements
C_f	post-failure fragment coefficient (lb^2-ms^4/$in.^8$)
$C_{r\alpha}$	peak reflected pressure coefficient at angle of incidence α
C_s	shear coefficient for ultimate support shear for one-way elements
C_{sH}	shear coefficient for ultimate support shear in horizontal direction for two-way elements*
C_{sV}	shear coefficient for ultimate support shear in vertical direction for two-way elements*
C_D	drag coefficient
C_Dq	drag pressure (psi)
C_Dq_o	peak drag pressure (psi)
C_E	equivalent load factor
C_H	shear coefficient for ultimate shear stress in horizontal direction for two-way elements*
C_L	leakage pressure coefficient
C_M	maximum shear coefficient
C_u	impulse coefficient at deflection X_u (psi-ms^2/$in.^2$)
C_u'	impulse coefficient at deflection X_m (psi-ms^2/$in.^2$)
C_v	shear coefficient for ultimate shear stress in vertical direction for two-way elements*
C_1	(1) impulse coefficient at deflection X_1 (psi-ms^2/$in.^2$) (2) parameter defined in figure (3) ratio of gas load to shock load
C_1'	impulse coefficient at deflection X_m (psi-ms^2/$in.^2$)
C_2	ratio of gas load duration to shock load duration
d	distance from extreme compression fiber to centroid of tension reinforcement (in.)
d'	distance from extreme compression fiber to centroid of compression reinforcement (in.)
d_c	distance between the centroids of the compression and tension reinforcement (in.)

* See note at end of symbols

d_e	distance from support and equal to distance d or d_c (in.)
d_i	inside diameter of cylindrical explosive container (in.)
d_l	distance between center lines of adjacent lacing bends measured normal to flexural reinforcement (in.)
d_{co}	diameter of steel core (in.)
d_1	diameter of cylindrical portion of primary fragment (in.)
D	(1) unit flexural rigidity (lb-in.) (2) location of shock front for maximum stress (ft) (3) minimum magazine separation distance (ft)
D_o	nominal diameter of reinforcing bar (in.)
D_E	equivalent loaded width of structure for non-planar wave front (ft)
DIF	dynamic increase factor
DLF	dynamic load factor
e	base of natural logarithms and equal to 2.71828...
$(2E')^{1/2}$	Gurney Energy Constant (ft/sec)
E	modulus of elasticity
E_c	modulus of elasticity of concrete (psi)
E_s	modulus of elasticity of reinforcement (psi)
f	unit external force (psi)
f'_c	static ultimate compressive strength of concrete at 28 days (psi)
f'_{dc}	dynamic ultimate compressive strength of concrete (psi)
f_{ds}	dynamic design stress for reinforcement (psi)
f_{du}	dynamic ultimate stress of reinforcement (psi)
f_{dy}	dynamic yield stress of reinforcement (psi)
f_s	static design stress for reinforcement (a function of f_y, f_u and θ) (psi)
f_u	static ultimate stress of reinforcement (psi)
f_y	static yield stress of reinforcement (psi)

* See note at end of symbols

F	(1) total external force (lbs) (2) coefficient for moment of inertia of cracked section (3) function of C_2 and C_1 for bilinear triangular load
F_o	force in the reinforcing bars (lbs)
F_E	equivalent external force (lbs)
g	variable defined in table 4-3
h	charge location parameter (ft)
H	(1) span height (in.) (2) distance between reflecting surface(s) and/or free edge(s) in vertical direction (ft)
H_c	height of charge above ground (ft)
H_c	scaled height of charge above ground (ft/$lb^{1/3}$)
H_s	height of structure (ft)
H_T	scaled height of triple point (ft/$lb^{1/3}$)
i	unit positive impulse (psi-ms)
i^-	unit negative impulse (psi-ms)
$\bar{i}_a$	sum of scaled unit blast impulse capacity of receiver panel and scaled unit blast impulse attenuated through concrete and sand in a composite element (psi-ms/$lb^{1/3}$)
i_b	unit blast impulse (psi-ms)
$\bar{i}_b$	scaled unit blast impulse (psi-ms/$lb^{1/3}$)
$\bar{i}_{bt}$	total scaled unit blast impulse capacity of composite element (psi-ms/$lb^{1/3}$)
$\bar{i}_{ba}$	scaled unit blast impulse capacity of receiver panel of composite element (psi-ms/$lb^{1/3}$)
$\bar{i}_{bd}$	scaled unit blast impulse capacity of donor panel of composite element (psi-ms/$lb^{1/3}$)
i_e	unit excess blast impulse (psi-ms)
i_r	unit positive normal reflected impulse (psi-ms)
i_r^-	unit negative normal reflected impulse (psi-ms)
i_s	unit positive incident impulse (psi-ms)
i_s^-	unit negative incident impulse (psi-ms)

* See note at end of symbols

I	moment of inertia (in.^{4})
I_a	average of gross and cracked moments of inertia of width b (in.^{4})
I_c	moment of inertia of cracked concrete section of width b (in.^{4})
I_g	moment of inertia of gross concrete section of width b (in.^{4})
I_m	mass moment of inertia (lb-ms^2-in.)
j	ratio of distance between centroids of compression and tension forces to the depth d
k	constant defined in paragraph
K	(1) unit stiffness (psi-in for slabs) (lb/in/in for beams) (2) constant defined in paragraph
K_e	elastic unit stiffness (psi/in for slabs) (lb/in/in for beams)
K_{ep}	elasto-plastic unit stiffness (psi-in for slabs) (psi for beams)
K_E	equivalent elastic unit stiffness (psi-in for slabs) (psi for beams)
K_L	load factor
K_{LM}	load-mass factor
$(K_{LM})_u$	load-mass factor in the ultimate range
$(K_{LM})_{up}$	load-mass factor in the post-ultimate range
K_M	mass factor
K_R	resistance factor
K_1	factor defined in paragraph
KE	kinetic energy
l	charge location parameter (ft)
l_p	spacing of same type of lacing bar (in.)
L	(1) span length (in.) except in chapter 4 (ft)* (2) distance between reflecting surface(s) and/or free edge(s) in horizontal direction (ft)
L_1	length of lacing bar required in distance s_1 (in.)

* See note at end of symbols

L_o	embedment length of reinforcing bars (in.)
L_w	wave length of positive pressure phase (ft)
L_w^-	wave length of negative pressure phase (ft)
L_{wb}, L_{wd}	wave length of positive pressure phase at points b and d, respectively (ft)
L_1	total length of sector of element normal to axis of rotation (in.)
m	unit mass (psi-ms^2/in.)
m_a	average of the effective elastic and plastic unit masses (psi-ms^2/in.)
m_e	effective unit mass (psi-ms^2/in.)
m_u	effective unit mass in the ultimate range (psi-ms^2/in.)
m_{up}	effective unit mass in the post-ultimate range (psi-ms^2/in.)
M	(1) unit bending moment (in-lbs/in.) (2) total mass (lb-ms^2/in.)
M_e	effective total mass (lb-ms^2/in.)
M_u	ultimate unit resisting moment (in-lbs/in.)
M_c	moment of concentrated loads about line of rotation of sector (in.-lbs)
M_A	fragment distribution parameter
M_E	equivalent total mass (lb-ms^2/in.)
M_{HN}	ultimate unit negative moment capacity in horizontal direction (in.-lbs/in.)*
M_{HP}	ultimate unit positive moment capacity in horizontal direction (in.-lbs/in.)*
M_N	ultimate unit negative moment capacity at supports (in.-lbs/in.)
M_P	ultimate unit positive moment capacity at midspan (in.-lbs/in.)
M_{VN}	ultimate unit negative moment capacity in vertical direction (in.-lbs/in.)*
M_{VP}	ultimate unit positive moment capacity in vertical direction (in.-lbs/in.)*

* See note at end of symbols

n	(1) modular ratio (2) number of time intervals
N	number of adjacent reflecting surfaces
N_f	number of primary fragments larger than W_f
p	reinforcement ratio equal to $\frac{A_s}{bd}$ or $\frac{A_s}{bd_c}$
p'	reinforcement ratio equal to $\frac{A_s'}{bd}$ or $\frac{A_s'}{bd_c}$
p_b	reinforcement ratio producing balanced conditions at ultimate strength
p_m	mean pressure in a partially vented chamber (psi)
p_{mo}	Peak mean pressure in a partially vented chamber (psi)
p_H	reinforcement ratio in horizontal direction on each face*
p_T	reinforcement ratio equal to $p_H + p_V$
p_V	reinforcement ratio in vertical direction on each face*
$p(x)$	distributed load per unit length
P	(1) pressure (psi) (2) concentrated load (lbs)
P^-	negative pressure (psi)
P_i	interior pressure within structure (psi).
ΔP_i	interior pressure increment (psi)
P_f	fictitious peak pressure (psi)
P_o	peak pressure (psi)
P_r	peak positive normal reflected pressure (psi)
P_r^-	peak negative normal reflected pressure (psi)
$P_{r\alpha}$	peak reflected pressure at angle of incidence α (psi)
P_s	positive incident pressure (psi)
P_{sb}, P_{se}	positive incident pressure at points b and e, respectively (psi)

* See note at end of symbols

P_{so}	peak positive incident pressure (psi)
P_{so}^-	peak negative incident pressure
$P_{sob}, P_{sod}, P_{soe}$	peak positive incident pressure at points b, d, and e, respectively (psi)
q	dynamic pressure (psi)
q_b, q_e	dynamic pressure at points b and e, respectively (psi)
q_o	peak dynamic pressure (psi)
q_{ob}, q_{oe}	peak dynamic pressure at points b and e, respectively (psi)
r	(1) unit resistance (psi) (2) radius of spherical TNT (density equals 95 lb/ft^3 charge (ft))
r^-	unit rebound resistance (psi)
Δr	change in unit resistance (psi)
r_e	elastic unit resistance
r_{ep}	elasto-plastic unit resistance (psi)
r_u	ultimate unit resistance (psi, for slabs) (lb/in for beams)
r_{up}	post-ultimate unit resistant (psi)
r_1	radius of hemispherical portion of. primary fragment (in.)
R	(1) total internal resistance (lbs) (2) slant distance (ft)
R_f	distance traveled by primary fragment (ft)
R_1	radius of lacing bend (in.)
R_A	normal distance (ft)
R_E	equivalent total internal resistance (lbs)
R_G	ground distance (ft)
R_u	total ultimate resistance
R_I, R_{II}	total internal resistance of sectors I and II, respectively (lbs)
s_s	spacing of stirrups in the direction parallel to the longitudinal reinforcement (in.)

* See note at end of symbols

s_1	spacing of lacing in the direction parallel to the longitudinal reinforcement (in.)
S	height of front wall or one-half its width, whichever is smaller (ft)
SE	strain energy
t	time (ms)
Δt	time increment (ms)
t_a	any time (ms)
t_b, t_e, t_f	time of arrival of blast wave at points b, e, and f, respectively (ms)
t_c	(1) clearing time for reflected pressures (ms) (2) container thickness of explosive charges (in.)
t_d	rise time (ms)
t_E	time to reach maximum elastic deflection
t_m	time at which maximum deflection occurs (ms)
t_o	duration of positive phase of blast pressure (ms)
t_o^-	duration of negative phase of blast pressure (ms)
t_{of}	fictitious positive phase pressure duration (ms)
t_{of}^-	fictitious negative phase pressure duration (ms)
t_r	fictitious reflected pressure duration (ms)
t_u	time at which ultimate deflection occurs (ms)
t_y	time to reach yield (ms)
t_A	time of arrival of blast wave (ms)
t_1	time at which partial failure occurs (ms)
T	duration of equivalent triangular loading function (ms)
T_c	thickness of concrete section (in.)
T_c	scaled thickness of concrete section ($ft/lb^{1/3}$)
T_N	effective natural period of vibration (ms)
T_r	rise time (ms)
T_s	thickness of sand fill (in.)

* See note at end of symbols

T_s	scaled thickness of sand fill ($ft/lb^{1/3}$)
u	particle velocity (ft/ms)
u_u	ultimate flexural or anchorage bond stress (psi)
U	shock front velocity (ft/ms)
v	velocity (in./ms)
v_a	instantaneous velocity at any time (in./ms)
v_b	boundary velocity for primary fragments (ft/sec)
v_c	ultimate shear stress permitted on an unreinforced web (psi)
v_f	maximum post-failure fragment velocity (in./ms)
v_f(avg.)	average post-failure fragment velocity (in./ms)
v_i	velocity at incipient failure deflection (in./ms)
v_o	initial velocity of primary fragment (ft/sec)
v_r	residual velocity of primary fragment after perforation (ft/sec)
v_s	striking velocity of primary fragment (ft/sec)
v_u	ultimate shear stress (psi)
v_{uH}	ultimate shear stress at distance d_e from the horizontal support (psi)*
v_{uV}	ultimate shear stress at distance d_e from the vertical support (psi)*
V	volume of partially vented chamber (ft^3)
V_d	ultimate direct shear capacity of the concrete of width b (lbs)
V_{dH}	shear at distance d_e from the vertical support on a unit width (lbs./in.)*
V_{dV}	shear at distance d_e from the horizontal support on a unit width (lbs/in.)*
V_o	volume of structure (ft^3)
V_s	shear at the support on a unit width (lbs/in)*
V_{sH}	shear at the vertical support on a unit width (lbs/in.)*

* See note at end of symbols

V_{sV}	shear at the horizontal support on a unit width (lbs/in.)*
V_u	total shear on a width b (lbs)
w	weight density of concrete (lbs/ft^3)
w_s	weight density of sand (lbs/ft^3)
W	charge weight (lbs)
W_c	total weight of explosive containers (lbs)
W_f	weight of primary fragment (oz)
W_{co}	total weight of steel core (lbs)
W_{c1}, W_{c2}	total weight of plates 1 and 2, respectively (lbs)
W_s	width of structure (ft)
WD	work done
x	yield line location in horizontal direction (in.)*
X	deflection (in.)
X_a	any deflection (in.)
X_e	elastic deflection (in.)
X_{ep}	elasto-plastic deflection (in.)
X_f	maximum penetration into concrete of armor-piercing fragments (in.)
X_f'	maximum penetration into concrete of fragments other than armor-piercing (in.)
X_m	maximum transient deflection (in.)
X_p	plastic deflection (in.)
X_s	(1) maximum penetration into sand of armor-piercing fragments (in.) (2) static deflection
X_u	ultimate deflection (in.)
X_E	equivalent elastic deflection (in.)
X_1	partial failure deflection (in.)
y	yield line location in vertical direction (in.)*

* See note at end of symbols

Z	scaled slant distance ($ft/lb^{1/3}$)	
Z_A	scaled normal distance ($ft/lb^{1/3}$)	
Z_G	scaled ground distance ($ft/lb^{1/3}$)	
α	(1)	angle formed by the plane of stirrups, lacing, or diagonal reinforcement and the plane of the longitudinal reinforcement (deg)
α	(2)	angle of incidence of the pressure front (deg)
β	(1)	coefficient for determining elastic and elasto-plastic resistances
	(2)	particular support rotation angle.(deg)
γ	coefficient for determining elastic and elasto-plastic deflections	
γ	deflections increase in support rotation angle after partial failure (deg)	
θ	support rotation angle (deg)	
θ	angular acceleration (rad/ms^2)	
θ_{max}	maximum support rotation angle (deg)	
θ_H	horizontal rotation angle (deg)*	
θ_V	vertical rotation angle (deg)*	
Σo	effective perimeter of reinforcing bars (in.)	
ΣM	summation of moments (in.-lbs)	
ΣM_N	sum of the ultimate unit resisting moments acting along the negative yield lines (in.-lbs)	
ΣM_P	sum of the ultimate unit resisting.moments acting along the positive yield lines (in.-lbs)	
μ	ductility factor	
ν	Poisson's ratio	
ϕ	(1)	capacity reduction factor
	(2)	bar diameter (in.)
ϕ_r	assumed shape function for concentrated loads	
$\phi(x)$	assumed shape function for distributed loads	

* See note at end of symbols

———	free edge
═══	simple support
$\overline{///////}$	fixed support
$\overline{XXXXXXX}$	either fixed, restrained, or simple support

* Note. This symbol was developed for two-way elements which are used as walls. When roof slabs or other horizontal elements are under consideration, this symbol will also be applicable if the element is treated as being rotated into a vertical position.

APPENDIX 3C

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