EARTHQUAKE DESIGN OF STUCTURES WITH BRITTLE MEMBERS AND HEAVY ARTIFICIAL DAMPING BY THE METHOD OF DIRECT INTEGRATION

D. A. Winthrop* and H. C. Hitchcock**

Introduction

This paper outlines an investigation by the New Zealand Electricity Department into possible methods of increasing the seismic strength of 220kV airblast circuit breakers. The circuit breaker was idealised as a two mass vibrating system whose behaviour in different earthquakes was examined by the method of direct integration of the equations of motion.

History

The circuit breakers had been purchased under a specification requiring a seismic design factor of 0.25g. However earthquake damage to similar breakers in a number of countries together with a more detailed understanding of the response of structures to earthquakes lead to the adoption by the New Zealand Electricity Department of standard design spectrum curves based on a set of single mass response spectra drawn up by Skinner(1).

These spectra were produced from the eight components of four well known earthquakes, El Centro 1940 and 1934, Olympia 1949 and Taft 1952. The records were scaled to the 1940 El Centro N-S size then their spectra were averaged and smoothed. The present N.Z.E.D. specification for equipment with brittle components requires them to withstand earthquake forces obtained from the appropriate design spectra curve with a factor of safety of at least two.

The La Ligua earthquake of 1965 (Chile), magnitude 7-7.5 on the Richter scale had its epicentre 80 miles from San Pedro substation where 8 airblast circuit breakers of a type in common use in New Zealand were extensively damaged. Out of a total of forty-eight 110kV support columns, thirty-eight were fractured at their base. Although the ground acceleration did not exceed an estimated 0.16g, the maximum response of the airblast heads was considered to be in the region 1.5-2.5g (ref.2). The New Zealand Electricity Department has over eighty of this type of breaker installed throughout the country, rated from 80kV to 245 kV. The maximum acceleration the 220kV circuit breaker porcelain columns can withstand is approximately 0.6g. The need for some form of strengthening of the columns became apparent after the San Pedro and similar incidents.

The manufacturer offered to supply vibration damping devices for fitting at the insulator column bases but because of the type of construction, the existing porcelain columns would also require replacing. The total cost of modifying each circuit breaker was such that alternative means of increasing the circuit breaker seismic resistance was sought.

One such proposal was to provide the circuit breaker base with a more flexible mounting together with heavy viscous damping. An elementary treatment of this arrangement was described in reference 3 and this suggests that large values of viscous damping in the support structure could to an appreciable extent make up for the lack of damping in the porcelain columns. When computer facilities became available the present more detailed study representing the circuit breaker as a two mass system was undertaken.

Method of Analysis of Circuit Breaker Response

Since the flexibility of the porcelain columns was not negligible and since their strength was limited, it was desired to obtain more definite information on the deflection and stressing of the porcelain by representing each pole of the breaker as a two mass system. The upper mass represents the three sets of airblast heads which are mechanically coupled so that they move virtually as one body and the lower mass represents the compressed air tank which forms the base of the circuit breaker.

It is difficult to determine the earthquake response of a two mass system with widely varying damping by modal analysis. Instead we studied the response of the two mass system to four of the earthquake records used by Skinner in obtaining his original response design curves.

The Department has available a package computer program known as Continuous System Modeling Program, or C.S.M.P. This is designed to simulate any continuous systems represented by one or more linear differential equations. C.S.M.P. has facilities for both linear and quadratic interpolation of ground acceleration from the digitised earthquake records. The first method was used by us primarily to limit computer operating time. The machine used for the operation was an IBM360/40 shared jointly by the New Zealand Electricity Department and the Ministry of Works.

Scaling of Accelerograms

Several methods of measuring the 'size' of an earthquake have been used.

(a) according to maximum ground acceleration

(b) according to the mean value of the velocity response spectrum between 0.1 and 2.5 seconds natural period for a value of damp-

* Engineer, New Zealand Electricity Department, Wellington.

** Senior Research Engineer, New Zealand Electricity Department, Wellington.

ing appropriate to the structure being considered (Housner).

(c) according to the mean value of acceleration response spectrum between 0.1 and 2.5 seconds for 2 percent critical damping (Skinner).

(d) according to the r.m.s. value of the strong motion portion of the accelogram (Jennings).

(e) according to the mean value of the velocity spectrum for 20% damping between 0.3 and 3 cycles per second plotted logrithmically (Plichon ref. 4).

The scaling factors indicated by the different methods are shown in Table 1. For our study we used the scaling factors generally as derived by Skinner but calculated from the period range applicable to our structure, namely 0.1 to 1.2 seconds. Table 1 shows that the difference between Skinners and the authors figures are small.

Application of Accelerograms

The two body arrangement representing the circuit breaker is shown in Fig. I. The equations of motion governing the systems are:

$$\ddot{X}_1 = -\ddot{Z} - \frac{X_1(K_1+K_2)}{M_1} - \frac{\dot{X}_1(C_1+C_2)}{M_1} + X_2\left(\frac{K_2}{M_1}\right) + \dot{X}_2\left(\frac{C_2}{M_1}\right)$$

$$\ddot{X}_2 = -\ddot{Z} + X_1\left(\frac{K_2}{M_2}\right) + \dot{X}_1\left(\frac{C_2}{M_2}\right) - X_2\left(\frac{K_2}{M_2}\right) - \dot{X}_2\left(\frac{C_2}{M_2}\right)$$

The maximum stress to which the columns is subjected are proportional to the maximum displacement of the circuit breaker head relative to the tank.

The structure was first subjected to the 1940 El Centro N-S acceleration record and the response of the airblast heads is shown on Fig III for different values of support structure stiffness and damping.

Scaled up versions of the other three earthquakes were then applied to the structure for the values of support structure stiffness most likely to be of interest. The circuit breaker haad response is shown on Fig. IV.

Conclusions

(1) Fig II compares Skinners response spectrum for 2% damping with the response spectra recalculated by us for four of the eight individual earthquakes which were scaled up by Skinner when deriving the standard. It suggests that the use of these accelerograms in direct integration methods is reasonably equivalent to the use of the design spectrum but is perhaps slightly on the optimistic side.

(2) Fig III shows that the greatest reduction in loading on the porcelain columns was given by high flexibility and damping. Damping even as high as 0.6 of critical gives an improvement. The curves showing the response of airblast heads to four earthquakes in Fig IV indicate:

(a) that the scatter of response for the four earthquakes decreases for heavy damping and low spring stiffness.

(b) that with 12000 ft/lb stiffness in the support and damping between 0.4 and 0.6 of critical, the response of the circuit breaker top to an El Centro sized earthquake is likely to be below 0.4g.

(c) That with 24,000 lb/foot stiffness and 0.55 damping which represents the recommendation of the earlier elementary study (3) based on the treatment of the circuit breakers as a single mass system, the response to two of the test earthquakes is as predicted by that study and to the other two is about 30% larger.

To limit the deflection of the circuit breaker due to wind forces, to about 1 inch at 90-100 m.p.h. it would be necessary to limit the stiffness of the supports to not less than 12000 lb/foot.

The results of this investigation confirm that by choosing supports of low stiffness and heavy viscous damping, a substantial improvement in circuit breaker seismic strength is possible. Preliminary investigations of the mechanical design indicate that the provision of these features is both practical and economic.

References:

(1) Skinner R. I. "Earthquake-Generated Forces and Movements in Tall Buildings". Bulletin 66, New Zealand Department of Scientific and Industrial Research.

(2) Novoa F. "Earthquakes and the Substation Equipment Arrangement and Specification," 1970 CIGRE conference.

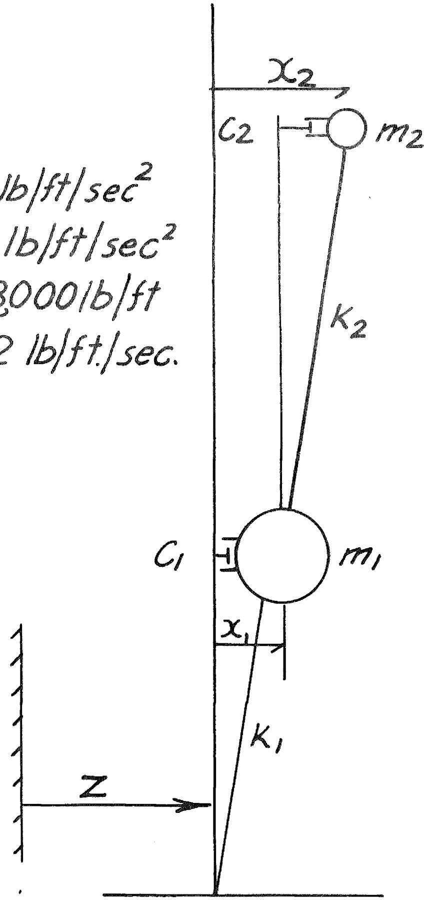
(3) Hitchcock H.C. "Electrical Equipment and Earthquakes" Jan. 1969 New Zealand Engineering.

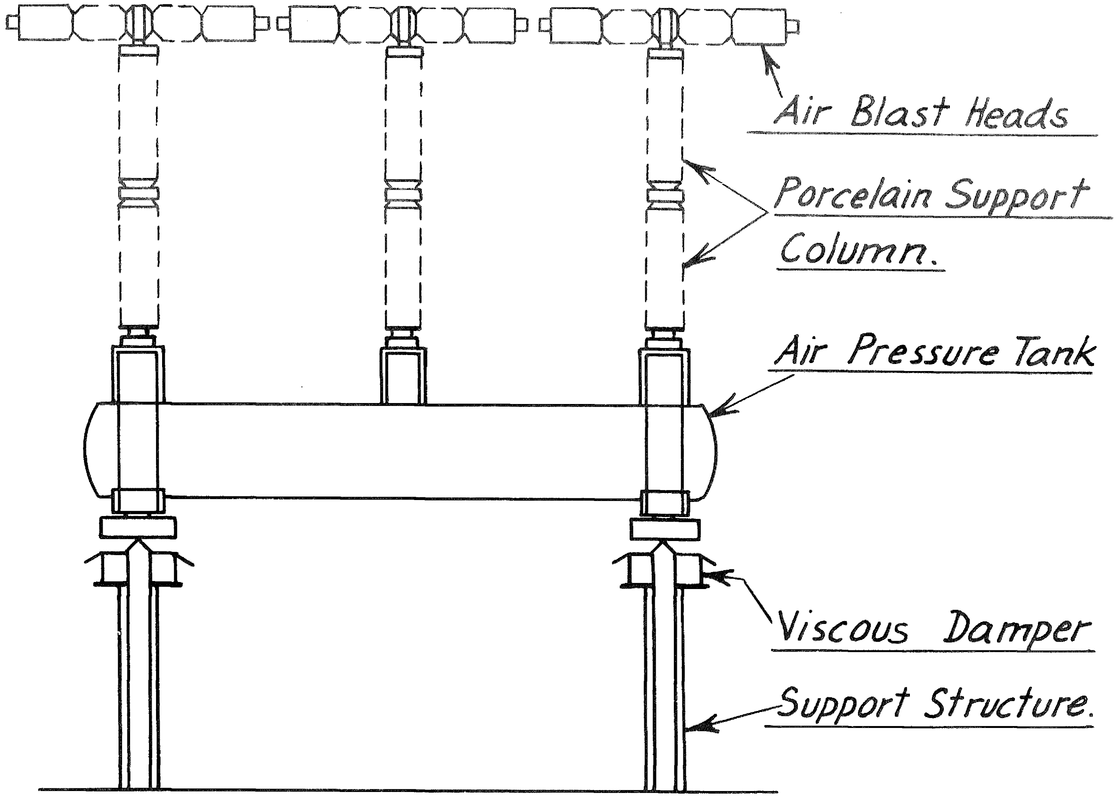
(4) Plichon C. E. "Dynamic Analysis of Nuclear Power Plant Behaviour to Seismic Excitation", 'Nuclear Engineering and Design' 1970 Vol.12.

TABLE 1

	EL CENTRO 1940 N.S.	OLYMPIA 1949 N10W	OLYMPIA 1949 N80E	TAFT 1952 S21W
Max Ground acceln	0.33	0.17	0.32	0.18
FACTOR	1.00	1.94	1.03	1.84
Spectral Intensity (Housner) Zero damping, 0.1-2.5 secs	8.94	5.59	6.05	4.53
FACTOR	1.0	1.6	1.48	1.97
Mean accel. response (Skinner) 2% damping 0.1-2..5 secs	1.3	0.74	0.91	0.59
FACTOR	1.00	1.75	1.42	2.19
Mean accel. response (Authors) 2% damping 0.1-1.2 secs	0.809	0.446	0.612	0.386
FACTOR	1.00	1.82	1.32	2.10
R.M.S. Accel. (Jennings)	2.20	1.57	1.95	1.42
FACTOR	1.00	1.4	1.13	1.55

$m_1 = 59\,lb/ft/sec^2$
$m_2 = 78\,lb/ft/sec^2$
$k_2 = 68{,}000\,lb/ft$
$c_2 = 92\,lb/ft./sec.$





Single Pole of Circuit Breaker

m_1, m_2 mass constants
k_1, k_2 stiffness constants
c_1, c_2 damping constants,
where $c = 2N\sqrt{m.k}$.
N is fraction of critical damping
x_1, x_2 displacements of m_1 and m_2.
z " of ground.

220kV. AIR BLAST CIRCUIT BREAKER

FIG. I

RESPONSE SPECTRA (0·02 DAMPING FACTOR)

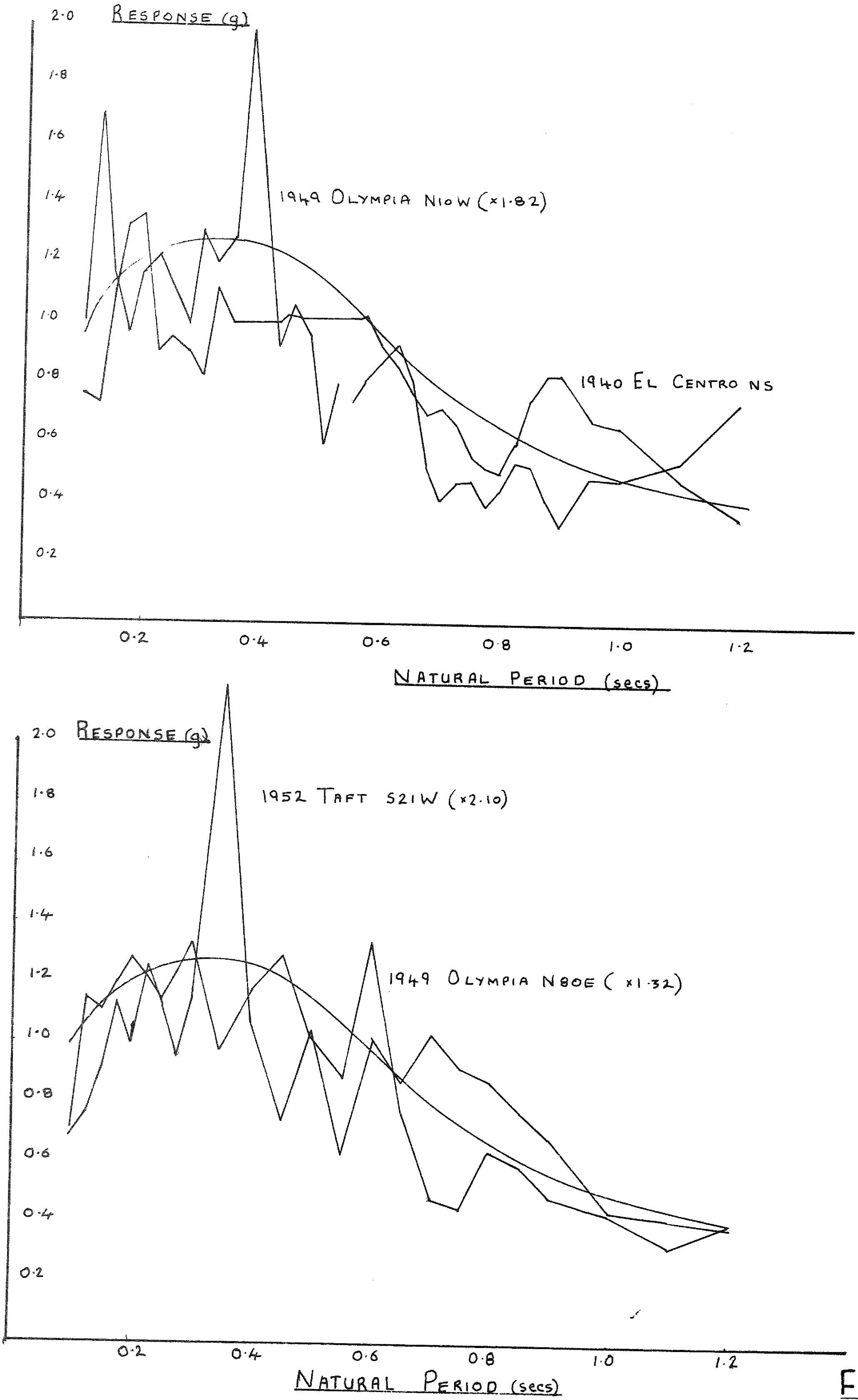


FIG II

RESPONSE OF AIRBLAST HEADS TO

1940 EL CENTRO CONDITIONS (N-S)

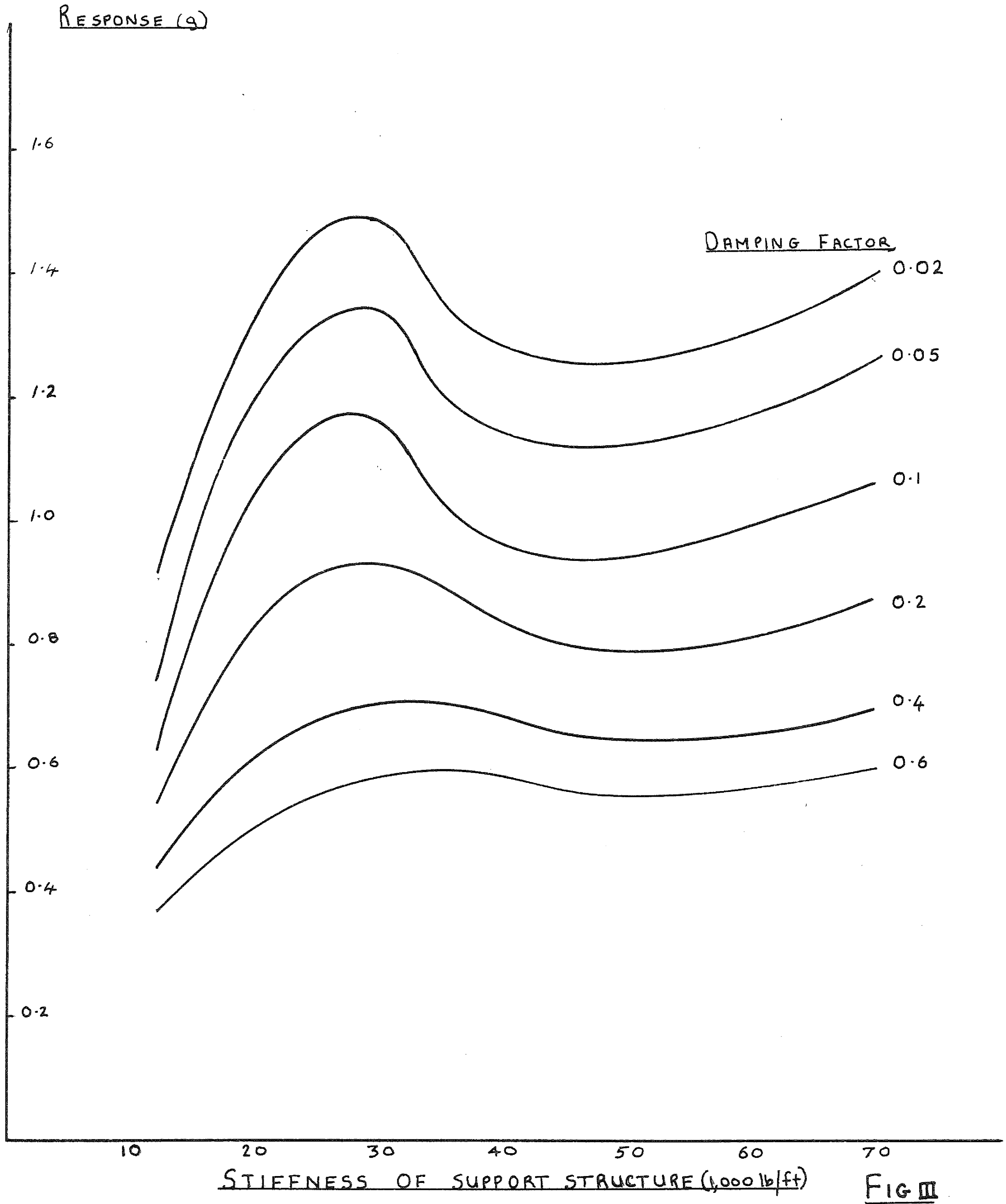


FIG III

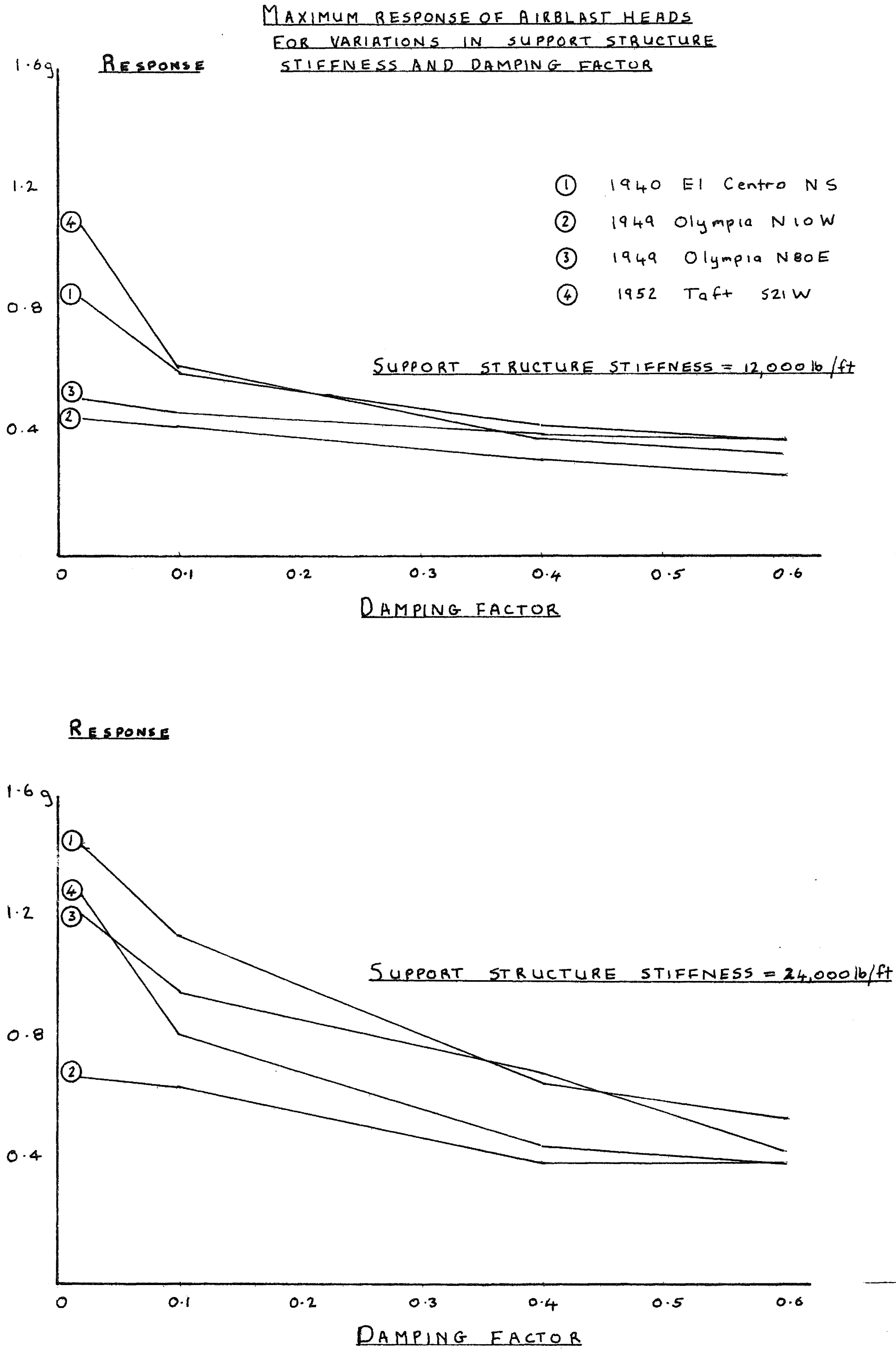

MAXIMUM RESPONSE OF AIRBLAST HEADS
FOR VARIATIONS IN SUPPORT STRUCTURE
STIFFNESS AND DAMPING FACTOR
RESPONSE
1·6g
1·2
0·8
0·4
① 1940 El Centro NS
② 1949 Olympia N10W
③ 1949 Olympia N80E
④ 1952 Taft S21W
SUPPORT STRUCTURE STIFFNESS = 12,000 lb/ft
0
0·1
0·2
0·3
0·4
0·5
0·6
DAMPING FACTOR
RESPONSE
1·6 g
1·2
0·8
0·4
SUPPORT STRUCTURE STIFFNESS = 24,000 lb/ft
0
0·1
0·2
0·3
0·4
0·5
0·6
DAMPING FACTOR

FIG IV