VIBRATION MEASUREMENTS OF 32,000 ton D. W. SUPER TANKER

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VIBRATION MEASUREMENTS OF 32,000 ton D. W. SUPER TANKER

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Abstract.—The present report deals with the results of the vibration measurements of 32,000 ton d.w. super tanker in trial trips. All the natural frequencies of the flexural and torsional vibrations up to the blade frequency were observed involving those of small amplitude measured by the Geiger vibrographs and the optical one which has been made on trial. Since the measured critical frequencies of the flexural vibration of the hull are almost proportional to the number of node in both cases of ballast and loaded conditions, it is pointed out that the higher modes of the hull vibration are considered to be of the shearing vibration. The theoretical investigations on the present observations in details are not presented except one of the computed result of the vibration profile of the higher mode of the shearing vibration of the hull as an example.

1. Introduction. Vibration measurements were carried out on 32,000 ton d.w. super tanker which had been built in Mitsubishi Shipbuilding & Engineering Co. Ltd., Nagasaki Works in the trial trips. The authors are obliged to the Intermarine Navigation Corporation Co. Ltd. the owner, and the Managers of Mitsubishi Nagasaki Works for permission to publish the paper. Valuable guidance and help is afforded by Prof. Y. Watanabe, Director of the Institute. They are also indebted to the assistance of Messrs. K. Ôtaka and H. Hiyama, assistants of the Institute, Messrs. S. Nishikawa, K. Ishii and the others of the engineers of Hull Designing Section of Mitsubishi Nagasaki Works in the phase of the measurements.

The objects of the vibration measurements are to investigate the vibration characteristics of the ship's hull and for obtain data to assist in devising new method of estimating the natural frequencies of the higher modes of the vibration in the vertical and horizontal planes and the torsional axis. The above objects are required in the stage of the initial design of the hull.

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The vibrations are measured by four Geiger vibrographs and a set of three elements vibrogroph (vertical, transverse horizontal and torsional) magnified by optical lever devised on trial by one of the authors.

Through all the trial trips, no undue vibration was measured except in the case of astern trial. The natural frequencies from the fundamental mode to nine nodes, to six nodes and to five nodes, in vertical, horizontal and torsional vibrations respectively are clearly recorded including the small amplitude of the vibration which could hardly be felt to human body in the present measurements. The critical frequencies of two noded mode of flexural vibrations was measured as well as the higher mode of vibration was recorded, however this is independent of the number of propeller revolution.

In regard to the analysis of the results of the measurements, since the natural frequencies clearly occur almost proportional to the number of nodes, the flexural vibration of the ship's hull in such a higher mode as which is excited by propeller blades is considered to be the ***shearing vibration.*** The analysis in details of this type of the vibration is not shown in this paper, but a mode of vibration is qualitatively presented as an example.

2. Paticulars of Ship and Measuring Procedure. The principal dimensions and the other items are shown as follows;

length over all	659′-11″	(201.143 M)
length between P. P.	630′- 0″	(192.024 M)
breadth	88′- 0″	(26.822 M)
depth	45′- 0″	(13.716 M)
draught	33′- 10¾″	(10.332 M)
dead weight	about 32,000 ton	
full displacement	about 42,300 ton	
main engine	one set of steam turbine with double-reduction gear, 15,000 SHP at 108 RPM	
propeller	4 bladed single screw	

The trial trips were taken place in four days and these loading conditions and etc. are shown in the following table.

sea trials	1st preliminary	2nd preliminary	1st official	2nd official
date (1955)	Jan. 29	Feb. 1	Feb. 12	Feb. 15
object	progressive speed trial	vibration measurement	progressive speed trial	progressive speed trial
loading condition	ballast	ballast	full loaded	full loaded
displacement (ton)	31,133 ~ 31,257	27,883 ~ 22,444	42,473 ~ 42,414	42,213 ~ 42,139

The measurements of the hull vibration were carried out during all the progressive speed trials, however, the second trial has been taken place especially for the object of vibration survey.

Two Geiger vibrographs and one optical vibrograph were located at the section of Fr. No. 20 and Fr. No. 18 respectively on the center line of upper deck, and the three Geigers were set on the economizer of main boiler, gunwale on upper deck, and boiler flat at the same number of the frame respectively for measurement of the coupled vibration of the boiler with economizer and the hull. In the second trial, two Geigers and optical vibrographs were shifting along the center line of upper deck from after end to fore perpendicular and measured the mode of the seven noded vertical vibration during the driving of constant propeller revolution. Two Geigers were located at F. P. on upper deck in the first preliminary trial.

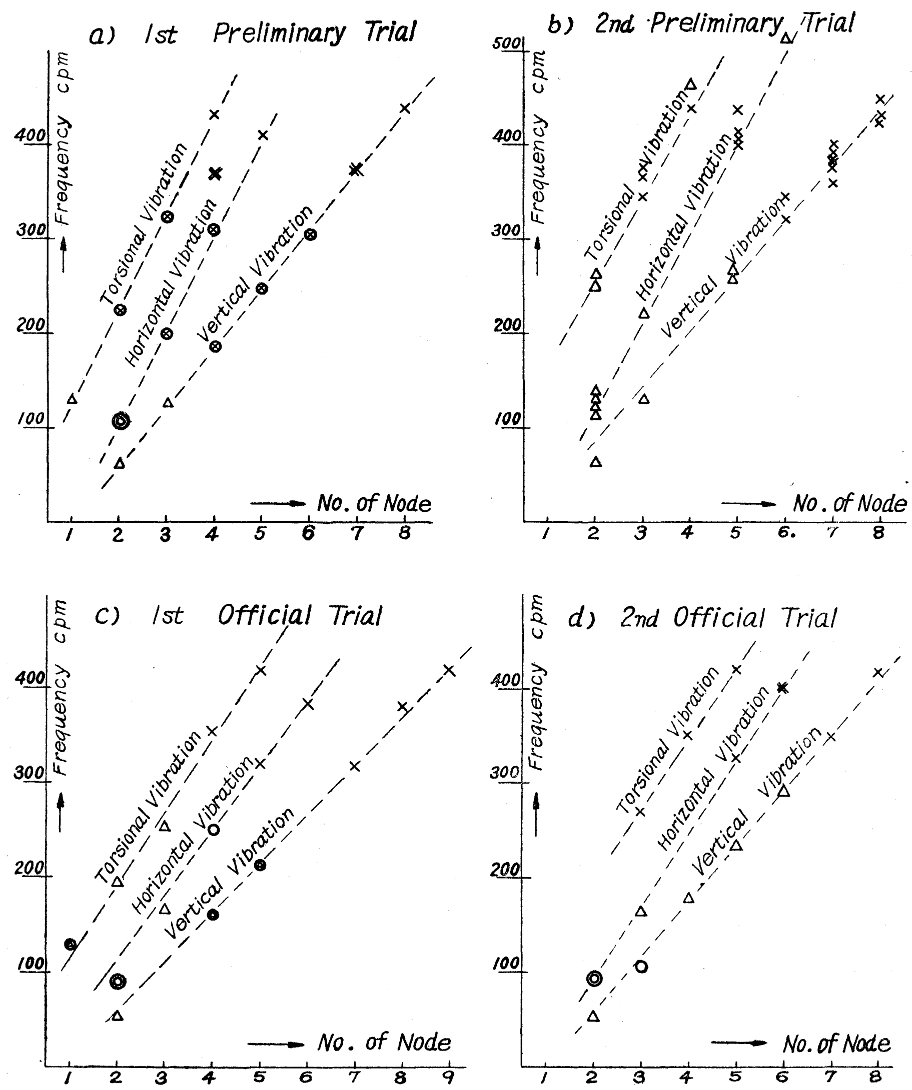
The rotational vibrograph for measuring the torsional angle of ship's hull used in the present measurements was devised on trial by one of the authors.[1] The set consist of three elements vibrographs, namely, vertical, transverse horizontal and rotational ones. The vibration displacements of three elements are recorded on an oscillogram at the same time with timer. Vertical and horizontal displacements are magnified about 30 times on the record and the rotational angle is recorded with the magnification of 10^{-3}rad. = 6.25 mm. The principle of this type of optical vibrograph of vertical and horizontal systems is the same as that of Leet seismograph.[2] The natural frequencies of three vibrographs in this set are about 40 vibrations per min. and the damping of the pendulums are satisfactorily given by the magnetic damper in three elements of vibrograph.

3. Results of Measurements. Fig. 1 a) $\sim$ d) show the natural frequencies of the hull which were measured in four days trial trips respectively. As will be seen in the figures, the critical frequencies from the fundamental mode to the higher mode which is excited by propeller revolution and the blade frequencies are clearly recorded. The remarkable amplitude of the vibration measured are found in two noded horizontal vibration, seven noded vertical vibration in the second preliminary trial trip, and four or five noded vertical and horizontal vibrations in astern trial in the present observations. It is clearly seen that all the critical frequencies of the flexural and the torsional vibrations are observed almost proportional to the number of nodes of the respective vibrations. Such results as observed in the present observation have also been obtained in the previous vibration measurements of 10,000 ton d. w. motor cargo vessel.[3]

1) T. Kumai, Reports of Western Society of Naval Architect, Japan. No. 10. 1955.

2) L. Don Leet, Earth Waves, Harvard University Press, 1950.

3) T. Okabe, Fujita, and Matsuyama; Reports of Western Society of Naval Architect, Japan. No. 6. 1953.



× Excited by blade frequency
o Excited by blade frequency, in astern trial
⊗ Excited by propeller revolution
Δ Independent of propeller revolution
⊛ Independent of propeller revolution, in astern trial
✱ Severe vibration excited by blade frequency
⊚ Severe vibration independent of propeller revolution

FIG. 1. Relation between measured natural frequencies and number of node.

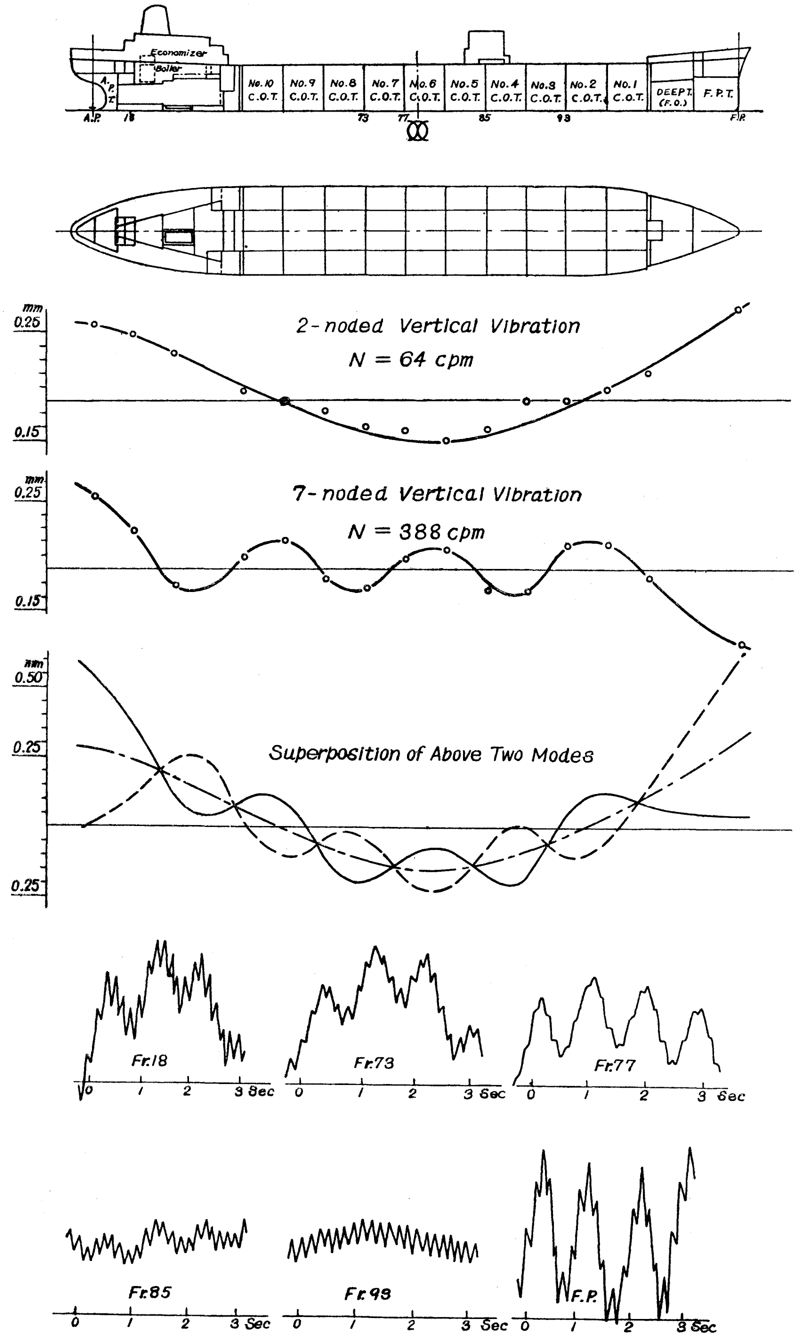


FIG. 2. Vibration profiles of 7-noded mode of vertical vibration with accompanying fundamental mode, and a copy of oscillogram of different types of the recording.

It is of interest that during the vertical vibration of seven noded mode resonant with propeller blade excitation, the fundamental mode is always excited by the other forces and this does not depend upon the number of the propeller revolution. The vibration profiles in the above measurements are shown in Fig. 2, in addition, several types of the recording of the vibration at the respective points of locations are shown in the same figure.

In the first trial, the vertical vibration which resonate with propeller blade frequency was presented in the stern of the ship, roughly over the half of her length. On going forward a slight distance, practically no perceptible motion of vibration could be felt. The same type of the stern vibration as the above mentioned was also measured in the horizontal vibration. In the second trial, no stern vibration was recorded, but the nodal mode of the vibration was clearly recorded as seven noded vertical vibration as will be seen in Fig. 2. It is supposed that the reason of the occurrence of these different modes which occur even in equal displacement of ship is respond of a delicate difference of the distributions of loading of cargo along her length.

The serious vibration excited by the blade frequency was recorded in the astern trial. Since this type of vibration is violent in the stern of the ship, it will easily be seen that the resonant vibration is excited by hydrodynamical periodic force on the hull surface of the run.

The natural frequencies of the torsional and the horizontal vibrations are plotted as shown in Fig. 1. The most approached values of the measured frequencies of these two types of the vibrations are considered to be that of coupled vibration, provided the axis of centre of gravity of ship along her length is not always coincide with that of the torsion centre of ship's hull. In the present ship, it is supposed that the critical frequency of torsional vibration of n-noded mode coupled with that of $(n+1)$-noded mode of horizontal one.

The relation between the displacement of the ship and the critical frequencies are plotted in Fig. 3 a), b), c) in the cases of vertical, horizontal and torsional vibrations respectively with the parameter of the number of nodes.

For corroborate the coupled vibration of the horizontal vibration of the hull and the boiler with economizer which installed with the boiler flat like as inversed pendulum, the measurements of the phase of both vibrations at the top of economizer and the boiler flat were taken place. However, the coupling action was not so considerable, because the natural frequency of the boiler with economizer as inversed pendulum is lower than that of the hull.

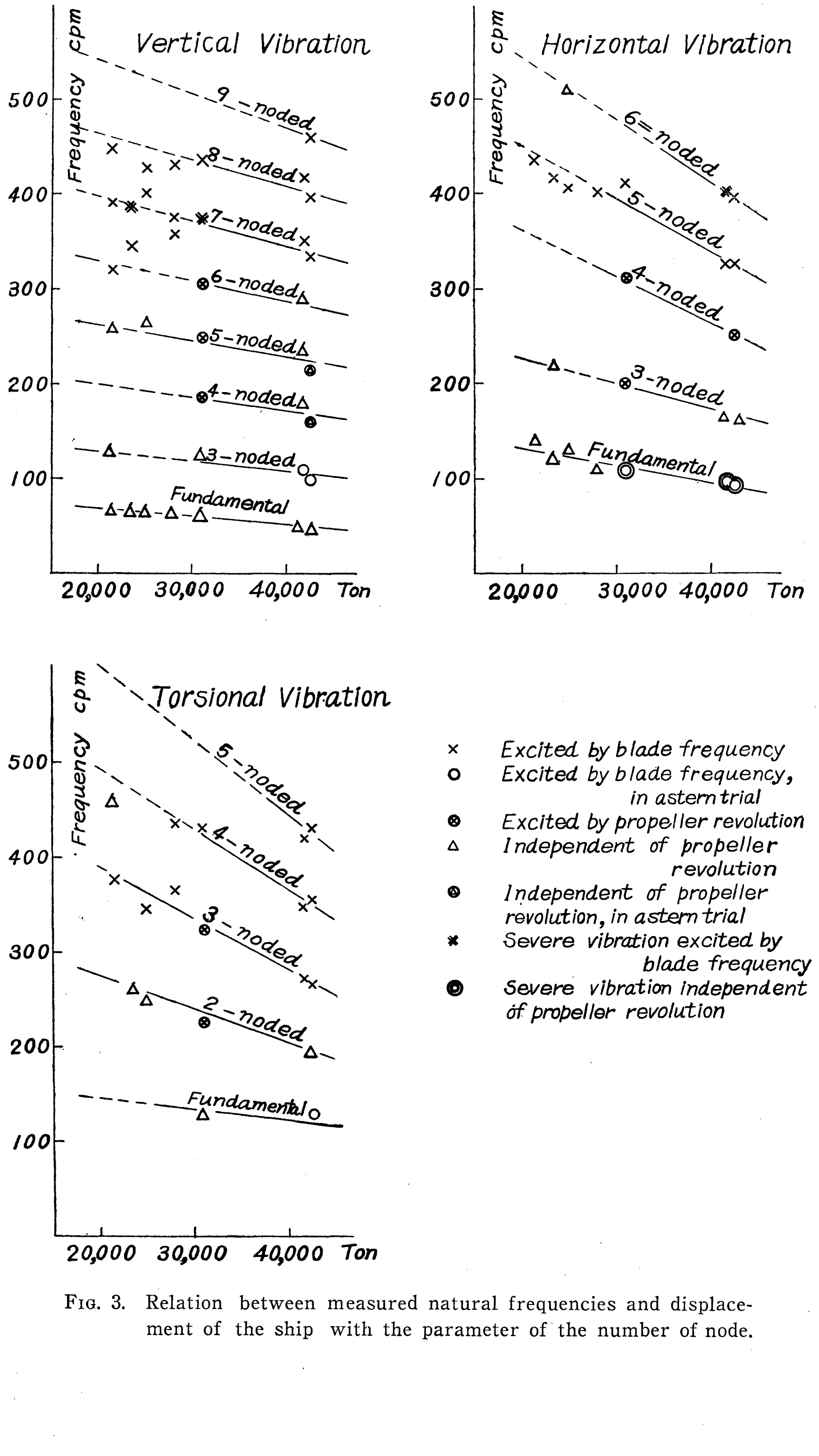
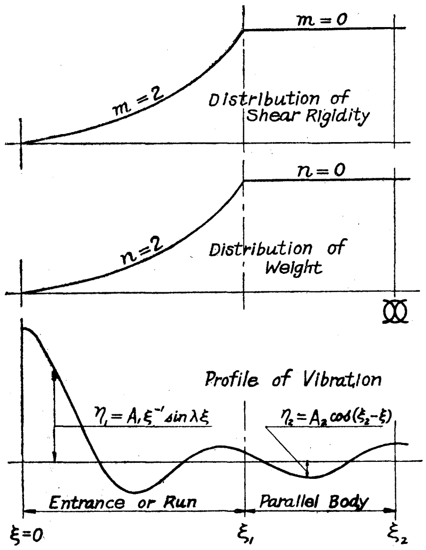


FIG. 3. Relation between measured natural frequencies and displacement of the ship with the parameter of the number of node.

4. Some investigations into the results of measurements. Since the natural frequencies occur proportional to the number of the nodes even in the higher modes of the flexural vibrations of the hull like as that of the torsional vibration as will be seen in Fig. 1, the higher mode of flexural vibration of the ship's hull is considered to be of the *shearing vibration* which has already been investivated by Prof. Suyehiro in the vibration of low buildings.[4] In the vibration of ship's hull, however, the effects of variable rigidity and non-uniform mass distributions should be taken into account for calculation of natural frequency and the mode of vibration. In the present investigation, one of the higher mode of the shearing vibration is qualitatively presented. If the shear rigidity and the mass are assumed to be distributed as power curves of m-th and n-th order respectively, and the length of the entrance or the run is taken as 30 % of the length of the ship, the mode of eight-noded vibration, for an example, is presented as shown in Fig. 4, provided $m=2$, $n=2$ are taken into account. The mathematical treatise on the shearing vibration is the same as that of the torsional vibration, which has been carried out by one of the authors in the previous paper provided the rotatory inertia of the section of the ship is ignored.[5] As will be seen in Fig. 4, when the shear rigidity decreases suddenly in the vicinity of the end of the hull, the vibration amplitude of this part becomes considerably large and the amplitude does not so remarkably depend upon the mass distribution in this position.



$$\eta = A\xi^{\mu} J_{-\frac{\mu}{\mu+\nu}}\left(\frac{\lambda_1}{\mu+\nu}\xi^{\mu+\nu}\right) + B\xi^{\mu} J_{\frac{\mu}{\mu+\nu}}\left(\frac{\lambda_1}{\mu+\nu}\xi^{\mu+\nu}\right),$$

where $\lambda_1 = \xi_1^{m-n}\lambda^2$, $\lambda^2 = \frac{\rho^2 \omega_0 L}{k_0 G A_0}$,

$\mu = \frac{1-m}{2}$, $\nu = \frac{1+n}{2}$.

FIG. 4. Calculated profile of eight noded mode of vibration in the case of shearing vibration.

Further investigations on the shearing vibration will be presented on the next report which will be published in near future.

The effects of the discontinuity of loading, for example, the pump room near midship or

4) K. Suyehiro. "Scientific and Technical Papers" p. 278. 1934.

5) T. Kumai "Estimation of Natural Frequencies of Torsional Vibration of Ships," previous paper of this report.

the empty cargo oiltank upon the vibration amplitude are also considerable. The general expression of this effect, however, is not so simple. Some examples of this calculation will be shown in the other report.

It will be clearly shown that one of the reasons of the stern vibration is due to the weakness for the shear rigidity as above mentioned. However, as the other reasons, the bearing force of the propeller shaft and the hull suction force due to propeller revolution, should be taken into consideration as vibration generating forces.[6] The problem on the stern vibration in astern trials will probably be solved by the further investigation on the measurements of the above exciting forces in actual ship or in the model.

5. Conclusions. 1). All the natural frequencies of the hull vibrations up to the blade frequency were recorded on the oscillograms of the optical vibrograph including those of small vibration amplitude. The considerable amplitude of the vibration was measured in the higher mode nodes of the flexural vibration. It is seen that the higher mode of the vibration is that resonant with the blade frequency.

2). The fundamental mode of the flexural vibration was recorded independently to the propeller revolution when considerably higher mode of the vibration occured by the blade excitation in the present measurements. However, since the period of the fundamental mode of the vibration is about one second, it could hardly be felt to human body notwithstanding the considerable amplitude.

3). The stern vibration was also measured as the higher nodal vibration, which occured depending on the mass distribution of the ship, that is to say it arose with great nicety respond to the variation of trim.

4). Since the flexural natural frequencies of the hull which measured in the present observation is almost proportional to the number of node of the vibration like as torsional vibration. It is decided that the flexural higher mode of the hull vibration is considered to be the shearing vibration. Under some assumptions of the distributions of the shear rigidity and of the mass along the length of the ship, the higher mode of the hull vibration was calculated as a qualitative example of the shearing vibration.

5). The serious vibration was measured in the astern trial. It will be seen that the cause of this undue vibration is due to the propeller blade excitation. However, it does not explain quantitatively without further investigations on the hydrodynamical periodic force on the surface of the hull due to the propeller revolution.

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6) F. M. Lewis, Trans. Soc. N.A.M.E., Vol. 43. 1935, and Vol. 44. 1936.