Pasadena, California
March 28, 1941

The Honorable John M. Carmody,
Administrator, Federal Works Agency,
Washington, D. C.

Sir:

The Board of Engineers appointed by you to
report on the Failure of the Tacoma Narrows Bridge have
made a complete investigation of the design, the behaviour
after completion and the failure of the structure. Our
report covering this investigation follows.

Respectfully submitted,

BOARD OF ENGINEERS

[Signatures]

Othmar H. Ammann
Theodore von Kármán
Glenn B. Woodruff
The Bank of Mexico has, in compliance with Article 4, Paragraph 3, of the General Rules of the Mexican Banking System, established the following exchange rate for April 14, 1985:

1 US Dollar = 32.50 Mexican Pesos

The exchange rate is effective as of April 15, 1985.

Signed:

[Signature]

Director General of the Exchange Agency

[Signature]

Financial Secretary of the Exchange Agency

[Signature]

[Signature]
SUMMARY OF CONCLUSIONS

As a result of the investigations which are described in detail in this report, we have reached the following conclusions:

1. The Tacoma Narrows Bridge was well designed and built to resist safely all static forces, including wind, usually considered in the design of similar structures. Its failure resulted from excessive oscillations caused by wind action.

2. The excessive vertical and torsional oscillations were made possible by the extraordinary degree of flexibility of the structure and of its relatively small capacity to absorb dynamic forces. It was not realized that the aerodynamic forces which had proven disastrous in the past to much lighter and shorter flexible suspension bridges would affect a structure of such magnitude as the Tacoma Narrows Bridge, although its flexibility was greatly in excess of that of any other long span suspension bridge.

3. The vertical oscillations of the Tacoma Narrows Bridge were probably induced by the turbulent character of wind action. Their amplitudes may have been influenced by the aerodynamic characteristics of the suspended structure. There is, however, no convincing evidence that the vertical oscillations were caused by so-called aerodynamic instability. At the higher wind velocities torsional oscillations, when once induced, had the tendency to increase their amplitudes.

4. Vertical oscillations of considerable amplitudes were first observed during the erection of the suspended floor and continued, at intervals, until the day of failure. While, at times, the resulting stresses in the stiffening girders were high, there is no evidence that any structural damage resulted. Under certain observed conditions very high stresses were caused in the ties which connected the suspended floor structure to the cables at mid-span.

5. It appears reasonably certain that the first failure was the slipping of the cable band on the north side of the bridge to which the center ties were connected. This slipping probably initiated the torsional oscillations. These torsional movements caused breaking stresses at various points of the suspended structure and further structural damage followed almost immediately. The dropping of the greater part of the suspended structure of the center span was made possible by the failure of the suspenders.
This was followed by the sudden sagging of the side spans with resulting bending and overstressing of the towers and of the side spans.

6. The suspension type is the most suitable and the most economical that could have been selected for the Tacoma Narrows Bridge. No more satisfactory location would have been chosen.

7. Both the Public Works Administration and the Reconstruction Finance Corporation were entirely justified in assuming that, because of the experience and reputation of the consultants employed by the Washington Toll Bridge Authority, there could be no possible question as to the adequacy of the design. Both agencies exercised thorough and competent supervision during the construction of the bridge.

8. There can be no question that the quality of the materials in the structure, and the workmanship, were of a high order.

9. Certain parts of the towers were severely overstressed and permanently deformed during the failure. While there is no visual evidence of damage to the cables, except at the center of the north cable, it is probable that they were overstressed during the torsional oscillations and as a result of the sagging of the side spans. The main piers were not damaged, except locally, during the failure and can withstand considerably heavier tower reactions than they received from the bridge as it existed. The anchorages were not damaged and are safe for forces not greater than those imposed by the original construction.

10. The criteria usually considered for rigidity against static forces do not necessarily apply to dynamic forces.

11. The remedial installations in the bridge represented a rational effort to control the amplitudes of the oscillations. Further installations, including diagonal stay ropes from the top of the towers to the floor were being investigated when the failure occurred, and these would have increased the rigidity. It is doubtful that any measures of this nature would have been sufficient to compensate for the extreme flexibility of the structure.

12. The evidence as to whether the vertical oscillations of the bridge would have been affected by fairing (streamlining) is inconclusive. There is certain evidence that fairing would have had an unfavorable influence on the torsional stability.

13. Further experiments and analytical studies are desirable to investigate the action of aerodynamic forces on suspension bridges.
14. Pending the results of further investigations, there is no doubt that sufficient knowledge and experience exists to permit the safe design of a suspension bridge of any practicable span. The results of further research should furnish knowledge that will permit of more economical design.

15. This report has been restricted to the Tacoma Narrows Bridge, except that available information from other bridges has been considered.