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SYNOPSIS The vibration a paper machine generates during normal operation presents a complicated challenge to engineers of paper machine support structures. The modeling and the analysis procedure inevitably involves many simplifications and assumptions. Therefore, a comparison of the calculated and the measured results is very helpful in assessing the validity of the overall approach.

This paper discusses correlation of calculated paper machine vibration with actual field measurements for a specific paper machine installation. A force-response analysis was performed using a commonly accepted industry practice which is generally considered to be conservative in several areas.

Subsequently, field vibration measurements were made. The vibration data were recorded at strategic locations of the paper machine and compared with the calculated values. The comparison confirms that the measured results are indeed conservative as compared to the calculated values. Key parameters that affect the predicted results are also discussed in the paper.

INTRODUCTION

The vibration a paper machine generates during normal operation presents an exciting challenge to structural engineers and designers of paper machine support structures. Since the support frame is non-rigid, and the excitation forces can not be totally eliminated, the vibration will always exist to some degree. The level of vibration depends not only on the relatively well defined rigidities of the steel and the concrete support frames, but also on other design parameters not very well defined. Examples of uncertainties are the flexibility and damping characteristics of the underlying soil, the magnitudes of unbalanced forces from the rotating rolls, and the reinforcing or counteracting of these forces from various rolls. Due to these and other variables, the calculation of vibration amplitudes inevitably involves many simplifications and assumptions. Therefore, a comparison of the calculated and the measured results is very helpful in assessing the validity of the overall approach. This comparison is also a very important step in establishing the confidence level of the analysis procedure.

The primary function of a paper machine foundation is to support the machine without permitting excessive vibrations during normal operation. For this reason, a force-response analysis is often performed in the foundation design process to predict the maximum response, to explore effective ways of minimizing the responses, and to assure that the maximum calculated response stays within the allowable limits set forth by the paper machine manufacturer.

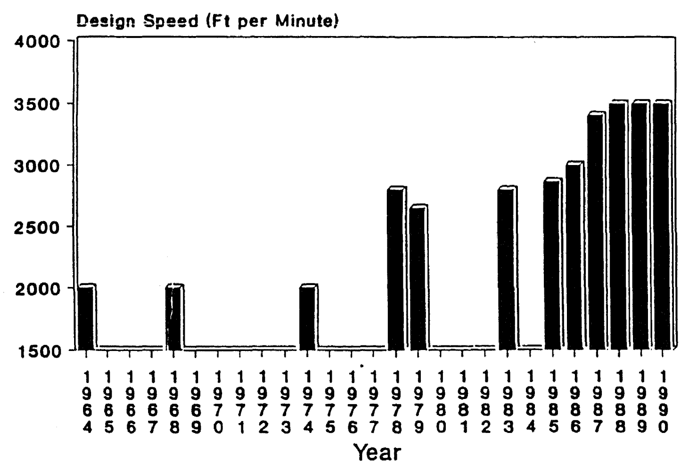

Fig. 1 Paper Machine Speed

In the past two decades, the speed and the width of paper machines have both increased significantly. Increases in speed and width as typified by one manufacturer are shown in Figs. 1 and 2 respectively. As the speed and the width of paper machines increased, the member sizes of machine frames were not increased proportionally. As a result, the safety margin of foundations decreased. As the safety margin decreases, an accurate prediction of the maximum response of a paper machine becomes a very important factor in assuring smooth operation of the machine and quality paper production.

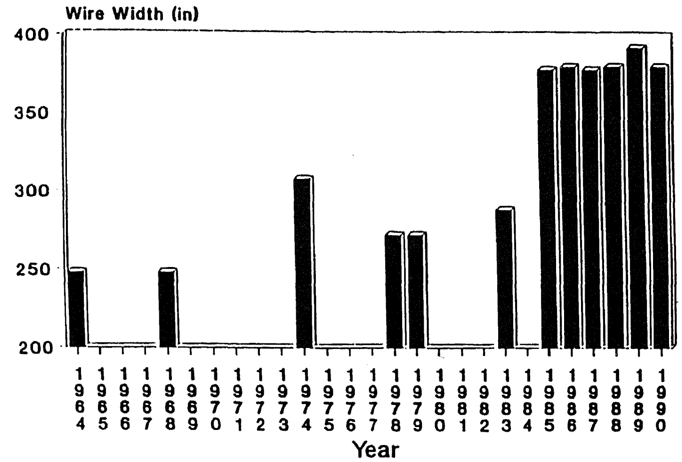

Fig. 2 Paper Machine Width

Prior to the 1980's, the dynamic analysis of paper machines and their supporting structures was generally done using a computer model that assumed fixed conditions at support column bases. In this approach, the flexibility of the underlying soil was not taken into account and the system frequencies were overestimated. This shortcoming was recognized and dynamic studies performed after 1980's on machine vibrations were generally made on an integrated system basis in which the machine frame, foundation, and soil properties were all included and the soil-structure interaction effect was properly taken into account.

This paper discusses correlation of calculated paper machine vibration based on analysis assumptions with actual field measurements for a specific paper machine installation. A force-response analysis was performed utilizing a complete model of a paper machine supported on a pile foundation. A commonly accepted industry practice which is generally considered to be conservative in the areas of damping and phase angle relationship of the unbalanced forces was used in the analysis.

Approximately one year after the paper machine was placed in operation, field vibration measurements were made at strategic locations of the paper machine to compare operating conditions to analysis predictions. A comparison of the measured and the predicted results is presented to show the level of conservatism for the case studied. Key parameters that affect the predicted results are also discussed in the paper.

COMPUTER ANALYSIS MODEL

The finite element model used in the computer analysis is shown in Fig. 3. As shown in the figure, the detail model above elevation 22 feet 3 in (6.76 m) was supplied by the machine manufacturer to represent the rigidity and weight distribution of the paper machine steel frame. The concrete structure below this elevation such as sill beams, columns and foundation mat were designed by Brown & Root. The beams and columns in the computer model were represented by prismatic finite elements. Since the stress levels of these members were generally low, uncracked section properties instead of transformed section properties were used. This is done to compensate for minute cracks that may exist in these concrete members.

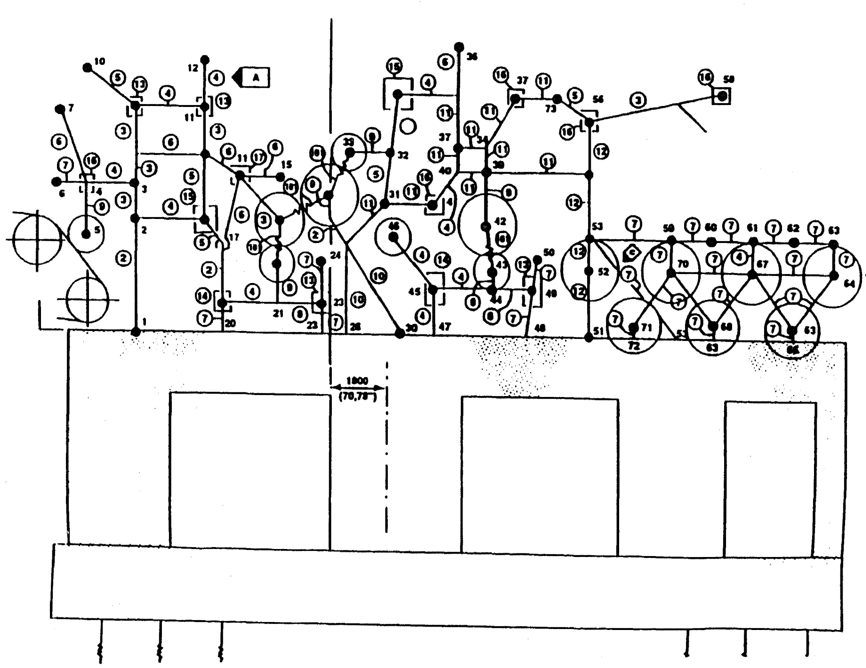

Fig. 1 Computer Analysis Model

The foundation was supported on 148 piles. The spring constants in the horizontal and the vertical directions were given by the soil consultant.

FORCE-RESPONSE ANALYSIS

Using the model described above, a force-response analysis was performed using the computer program STRUDL (ICES-STRUDL, 1976) and an in-house computer program. Sufficient modes were specified in the frequency calculation to assure that all significant modes were included in the modal combination. Furthermore, additional modes were added in separate sensitivity analyses to assure that the change of results with additional modes were insignificant.

Unbalanced force for each machine roll were given by the machine manufacturer. These excitation forces were assumed to be in-phase for rolls of the same size, i. e. all forces from rolls of same diameter were applied in the same direction simultaneously in the analysis. The velocity responses from rolls of other sizes were analyzed separately, group by group, in the same manner. Overall results from rolls of all sizes were then obtained by combining the group results using the square-root-of-the-sum-of-squares (SRSS) rule.

FIELD INVESTIGATION

Approximately one year after the machine was placed in operation, a field investigation was made to assess the performance of the machine. An IRD vibration analyzer (IRD,1985) was utilized to record the vibration signatures.

The purpose of the field investigation was three fold:
A) to assure that the vibration level was within the industry standard and below the allowable limits specified by the manufacturer.
B) to record the vibration signatures for future trouble shooting and reference.
C) to compare the calculated values to the field measured results.

At the time of vibration measurement, the paper was operating at a speed of about 3000 feet per minute (914.6 meter per minute). At this speed, the machine was operating smoothly without visible excessive vibration. The routine field investigation procedure was carried out. No complaints were raised and the temperature at accessible bearing housing was normal. Vibration signatures were recorded at high vibration areas and at locations where calculated results were available for comparison.

COMPARISON OF RESULTS

The maximum allowable vibration amplitude was specified by the manufacturer to be 1 mill (25 μm) in single amplitude on top of the sill beam, or 2 mills (50 μm) peak-to-peak. The maximum vibration amplitude calculated at this elevation using the procedures described above was 0.8 mills (20 μm) peak-to-peak. The maximum vibration amplitude measured at this elevation was 0.5 mills (13 μm) peak-to-peak.

DISCUSSIONS AND CONCLUSIONS

From the data as shown above, the calculated amplitude was higher than the measured amplitude. The procedure used in the analysis of paper machine on piles appears to be adequate for this particular case studied. The authors had investigated another paper machine foundation supported on soil (Bohinsky et al., 1991) and also found that the calculated responses were higher than the measured responses. However, the safety margins are inconsistent. It is cautioned that these two case studies provide two data points in the assessment of the procedure and should not be generalized to produce a prematured conclusion.

Current paper machine foundation design practice is to use a conservative approach in dealing with parameters that are not well defined. However, loads typically specified by machine manufacturers may not reflect unbalanced forces generated after wear and tear following many years of service. Further research and development work in the areas of damping, excitation forces and their combinations, acceptance criteria etc., is needed to improve the current procedure.

REFERENCES

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