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Vibration and Serviceability in Post Terminal Buildings

Vibrations et aptitude au service dans les bâtiments postaux

Gebrauchsfähigkeit und Schwingungen in Postabfertigungsgebäuden

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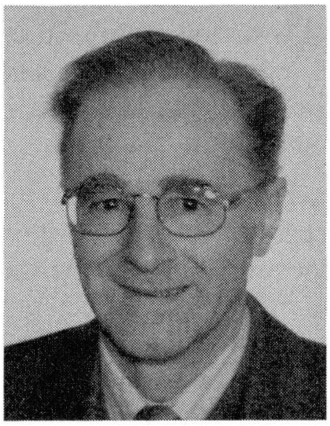

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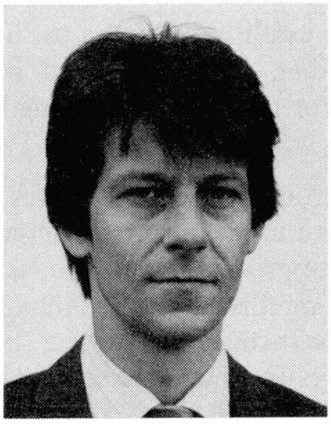


Sven Ohlsson, born 1952, received his civil eng. degree at Chalmers Univ. 1977, where he also received his doctoral degree and later was acknowledged the title associate professor. He has been active in structural research focused on dynamic problems and is presently in charge of the unit for Dynamics in Design at Chalmers.

SUMMARY

Buildings intended for mixed activities, such as Swedish post terminals, need special attention to assure a serviceable indoor environment. Vibration is a potential serviceability problem and it is adressed here. Typical activities in post terminals are reviewed and common structural configuration is described. Forklift transportation and handling of goods cause dynamic service loads. Past and presently undertaken experimental studies show that adequate structural systems, smooth floor surfaces and proper design are essential to avoid annoying vibrations. The need for better knowledge about dynamic design loads is urgent.

RESUME

Les bâtiments destinés à des activités variées, tels que les bâtiments postaux suédois, requièrent une attention particulière afin d'offrir de bonnes conditions de travail. Les vibrations représentent un problème potentiel pour l'aptitude au service. Les activités habituelles dans les bâtiments postaux et les dispositions constructives types sont présentées. Le transport par chariot élévateur et le traitement des marchandises provoquent des charges dynamiques. Etudes et expériences montrent que des systèmes structuraux adéquats, des surfaces de plancher molles et un projet bien conçu sont essentiels pour éviter les vibrations désagréables.

ZUSAMMENFASSUNG

Gebäude, die für gemischte Aktivitäten vorgesehen sind, wie schwedische Postabfertigungsanlagen, brauchen besondere Aufmerksamkeit, um gute Arbeitsverhältnisse zu garantieren. Schwingungen geben ein mögliches Problem der Gebrauchstauglichkeit, das hier behandelt wird. Typische Aktivitäten in Postterminals werden übersichtlich diskutiert und gewöhnliche Tragwerkslösungen werden beschrieben. Gabeltransporter und Güterabfertigung verursachen dynamische Gebrauchslasten. Experimentelle Studien zeigen, dass zweckmässige Tragwerkssysteme, weiche Fussbodenflächen und gebrauchsgerechte Konstruktionslösungen wesentlich sind, um störende Schwingungen zu vermeiden.

1. INTRODUCTION

Vibration as a potential source of reduced serviceability is described in relation to buildings which are supposed to accommodate multiple activities. The building type in focus - Swedish post terminal buildings - typically contains light industrial activities including indoor traffic as well as offices and even separate areas for physical fitness training. Typical activities and structural systems will be described. Short summaries of dynamic studies will also be given.

2. POST TERMINAL BUILDINGS

2.1 Activities

2.1.1 Post handling activities

A general overview is given in [1]. The activities at Årsta post terminal in Stockholm are described here as an example. 35 000 post items arrive daily. The post is mainly delivered by lorries to the terminal. It is contained in mailbags and wheeled post containers. The containers are used for mailbags containing letters and for parcels. The total terminal area is 37500 m^2 distributed between five stories. Two stories are used for post handling activities.

The ground floor includes a loading dock for lorries and two machine sorting lines for arriving mail. They are used for a first preliminary sorting with respect to letter size and item type. Furthermore the ground floor includes three machine sorting lines for mail leaving the terminal. The sorted mail is put into mailbags or post containers. One of these lines includes a robot station where sorted post parcels (boxes) are automatically put into containers. The first floor accomodates five machine sorting lines and one which is manually operated.

Post containers are continuously (day and night) transported across the ground floor to different stations by 8 forklift trucks. Each forklift will typically carry out 150 - 200 transportation tasks daily. A forklift weighs 27 kN and a post container adds a weight of 3 to 8 kN. The post is transported between the ground floor and the first floor by use of overhead conveyors. Except for forklift drivers, 15 persons are working on each floor at a time.

Fig. 1 Ground floor view

2.1.2 Office areas

There is a need for a foremans office where planning activities and computer support are based. These office rooms need to be located close to the post handling activities. The solution has been to accomodate this office on a mezzanine deck, which is located between the ground floor and the first floor and suspended from the first floor. This office space may experience vibration which may reduce the serviceability.

No complaints about vibrations have been noted from the more regular office areas in the terminal.

2.1.3 Physical training area

Several of the post terminals include an area which is planned for physical training. Such physical excercises typically occur during office hours. This severe dynamic loading may result in annoying vibration if this aspect is overlooked in the structural design, cf. references [2] and [3].

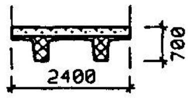
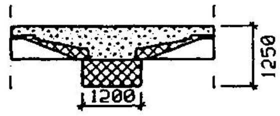
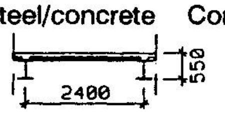
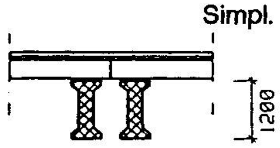
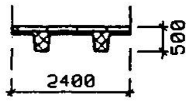
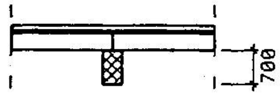
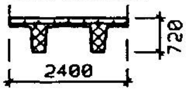
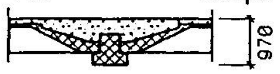
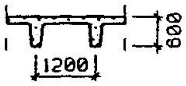
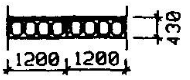
2.1.4 Activity - response cases

A typical terminal is supposed to accomodate a variety of activities, some of which are expected to induce substantial dynamic loads under service conditions. The most important dynamic load sources are vehicle loads from forklifts, goods handling loads from loading and reloading post containers and footstep forces from physical training. Humans are the most important critical sensors of resulting vibration. Other sensitive objects include automatic equipment for weighing and sorting letters.

2.2 Typical structural design of post terminals

The building has typically a beam-column type structure. Columns are often supporting floor bays of, say 12 x 12 m^2 unobstructed area. Various examples of cross sections for floors supporting forklift truck traffic and fitness training, respectively, are given in Table 1.

Table 1. Sample floor designs - Forklift goods handling and fitness training

Terminal	**Deck structure** Type	Span (m)	**Girder** Type	Span (m)	**Mass** (kg/m²)	f_1 (Hz) Calc.	Meas.	**Employee reaction**
Tomteboda ground floor (1982)	PC TTK240/50 + 200mm RC 	12.0 Cont.	PC RB120/50 + RC 	13.0 Cont.	1000 (Deck: 830)	7.5	-	None (forklift traffic floor)
Tomteboda sec. floor	Composite steel/concrete 	12.0 Cont.	PC I-beams 	16.8 Simpl.	600 (Deck: 410)	4.7	-	Some (forklift traffic floor)
Borås (1988)	PC TT240/40 + 100mm RC 	10.0 Simpl.	PC RB40/70 Rect beams 	8.0 Simpl.	580 (Deck: 510)	7.9	-	Some (forklift traffic floor)
Norrköping (1991)	PC TTK240/60 + 120 mm RC 	14.0 Cont.	PC FB70/70 + RC 	6.0 Simpl.	780 (Deck: 680)	8.7	10.0	None (forklift traffic floor)
Årsta (1991)	RC TTSwedeck 	12.0 Cont.	Steel girders concr covered 	10.7 Cont.	550 (Deck: 500)	6.8	7.8	Some (forklift traffic floor)
Linköping (1992)	PC HD120/32 + 140 mm RC 	10.0 Simpl.	PC FB70/80 	12.0 Simpl.	800 (Deck: 740)	6.5	-	New build. (physical training floor)
Västerås (1992)	PC HD120/38 + 50 mm RC 	12.0 Cont.	Steel HSQ55/35 	9.0 Simpl.	600 (Deck: 600)	5.0	-	None (physical training floor)

3. VIBRATION STUDIES OF THE ÅRSTA POST TERMINAL

3.1 Experimental program

The post terminal at Årsta was completed in 1991. Dynamic measurements were conducted at two different times. The first set of measurements was carried out during the summer of 1989. The main parts of the building structure were then erected. A second set of measurements was made in January 1991, when the building was finished. The studies are reported in [4]. The following three basic types of dynamic tests were carried out:

a. Forced vibration tests with subsequent limited experimental modal analysis aiming at modal parameters such as resonance frequencies f_n, modal damping ratios $(c/c_{cr})_n$ and mode shapes Φ_n for some of the lower floor vibration modes n.

b. Vibration tests with simulated service loads from forklift operations aiming at estimates of floor vibration levels related to different goods handling activities and forklift types.

c. Vibration tests using different dynamic loads aiming at establishing dimensionless transfer functions between different floor areas and between floors belonging to different stories.

Besides these three types of testing with corresponding aims, there were two benefits from repeating the testing at two different times. It enabled comparisons between a construction stage ('clean' structure) and a completed stage and between a relatively fresh stage and a later stage were some cracking and increase in Youngs modulus for concrete could have been expected.

3.2 Sample measurement records and results

A value for the fundamental frequency f_1=7.8 Hz was found for the floor area with 12 m span intended for forklift activity [4, 1989]. The second test series showed the same value for the fundamental frequency [4, 1991]. By 'the same' is meant identical within the two-digit accuracy. Higher modes were closely spaced, f_2=8.5 and f_3=9.0 Hz. The values for the experimentally measured natural frequencies are in fairly good agreement with theoretically calculated values based on the assumption about fully effective floor element cross sections (no cracks). Damping ratios c/c_{cr} for corresponding modes were evaluated to 1.3%, 1.2% and 1.7% respectively [4, 1991]. These values are rather typical (including the scatter) for this type of construction.

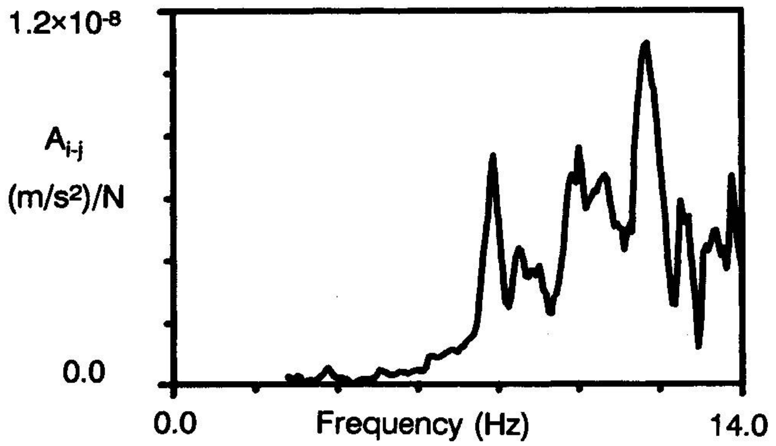


Fig. 2 Magnitude of accelerance function $A_{i\text{-}j}$ for two locations i,j at ground floor of the Årsta post terminal

Two conclusions may be that the floor area in question is basically uncracked even after it had experienced some static and dynamic service loads and that no substantial effective increase in concrete stiffness has occurred due to ageing. The risk of future cracking and corresponding reduction in resonance frequencies may of course not be neglected. The experimental values found for damping ratios support the previous suggestion of c/c_{cr}= 1% for design purposes.

The vibration tests which utilized forklift traffic as a simulated service load were carried through for a number of prescribed driving paths and manoeuvres. They also included two different forklift types. Examples of acceleration measurements at the ground floor in the

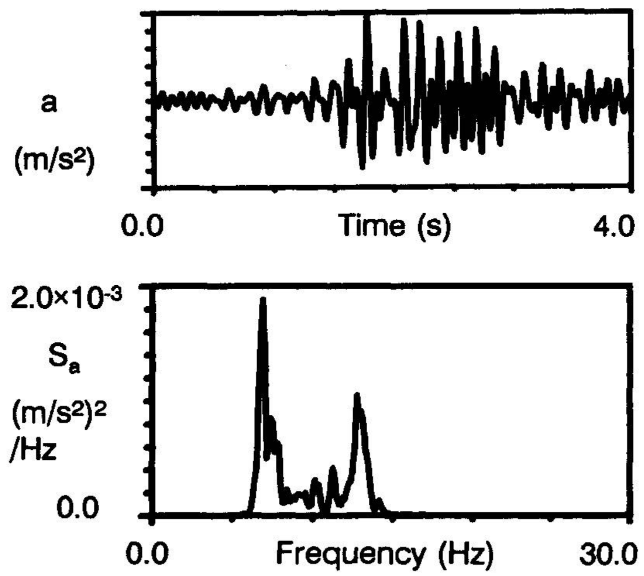


Fig. 3 Acceleration time record (±0.5 m/s²) and corresponding acceleration spectral density S_a for ground floor due to regular driving of a forklift of type AT.

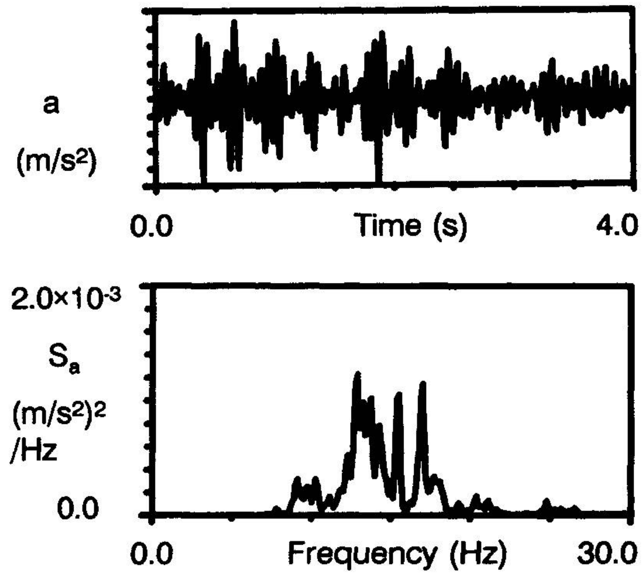


Fig. 4 Acceleration time record (±0.5 m/s²) and corresponding acceleration spectral density S_a for ground floor due to regular driving of a forklift of type Rocla.

vicinity of the driving area for the forklift are presented in Figs. 3 and 4 (after [4] 1991). It is worth noting that the softer wheels of the forklift of type AT result in a low-frequency dominated acceleration spectrum, basically limited to the frequency band 5 - 15 Hz, while the corresponding frequency range for the forklift type Rocla is aproximately 8 - 30 Hz. From Fig 3. it is clear that the spectral function shows a pronounced peak around 6.5 Hz. Closer studies have shown that this is not an effect of a floor resonance, but rather originates from the dynamic characteristics of the vehicle. This peak appears in vibration spectra for different floor areas and it changes only when the load carried by the forklift is altered.

Vibration levels of some sort must be established in order to estimate the possible violation of full serviceability. The ISO standard [5] is probably the document which is most widely acknowledged in this context. It recommends the use of frequency-weighted rms values for vibration acceleration as the main vibration parameter representing the annoying effect on people. Such values are, however, strongly depending on the averaging time used. The time dependence certainly needs more research attention. A time interval of 1 minute was chosen in [4] for such averaging. A total of maybe an hour of acceleration recordings was taken. Subsequent processing identified a minute for each loading case and floor area which yielded the highest frequency-weighted rms value. For the floor and forklift types here, typical such values were evaluated to somewhere between 0.02 and 0.05 $(m/s^2)_{rms}$. They may be compared to the limiting value of 0.04 $(m/s^2)_{rms}$ recommended for 'workshops' given in [5]. The result of such a comparison is basically in agreement with the practical experience here; Vibrations of this character and magnitude usually seem to be acceptable to the personnel involved in goods handling, but would be annoying to someone in an office-like environment.

4. CONCLUSIONS AND RESEARCH NEEDS

The experience gained from the operation of Swedish post terminals is here combined with some results from research and some specific experimental studies carried out in a couple of these terminals. The result is presented in a condensed form.

Building areas for different purposes such as goods handling and offices should be structurally decoupled as much as possible. This may be achieved by the use of moment-free joints between adjacent floor spans and by avoiding the use of non-supported partitions of full storey height, which could transfer vibration from a dynamically loaded floor to a floor supporting more quiet activities, e.g. an office.

Mezzanine decks should not be suspended from floor spans which experience dynamic service loads. Measurements at Årsta post terminal confirmed this for a case where an office floor is suspended from the floor above, which was designed to withstand forklift traffic.

Floor surfaces should be smooth and in level if they are supposed to carry traffic loads. Methods for the specification, execution and verification of such high quality surfaces are needed and further research is welcome in this area.

It is of great value to be able to compare subjective judgements, vibration measurements and theoretical calculations for floors of different construction supporting similar type of activities. Such comparisons have been made and will be continued aiming at simplified design methods for vibration serviceability.

Floors with a relatively high bending rigidity in a direction perpendicular to the span direction have better dynamic properties than floors with a more pronounced anisotropy. For concrete floor elements with a TT-shaped cross section, improvement can be achieved by adding a structurally effective (at service load level) concrete topping.

ACKNOWLEDGEMENTS

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