Designing reinforced concrete floors for serviceability

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Dimensionnement des planchers en fonction de l'aptitude au service

Bemessung von Stahlbetondecken auf Gebrauchstauglichkeit

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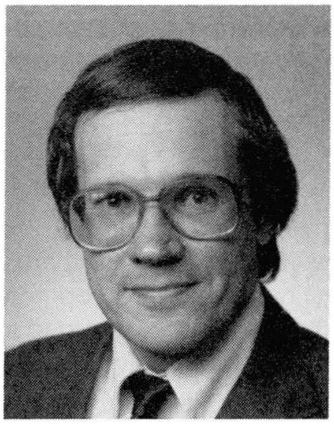

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SUMMARY

Serviceability performance of reinforced concrete floor systems must be incorporated into the design of the structure under certain parameters to avoid excessive long-term deflections. When such floor systems are subject to sustained loads, are non-continuous, or contain long spans, the design and detailing concepts must provide for structural serviceability to ensure adequate long-term performance.

RESUME

En vue d'éviter des flèches excessives à long terme dans une structure porteuse, il faut intégrer sous certaines conditions l'aptitude au service dans le dimensionnement des systèmes de planchers en béton armé. Tel est le cas lorsqu'il s'agit de structures à forte proportion de charges permanentes, à éléments uniquement isostatiques ou à longues portées; le calcul et la conception des détails doivent alors prendre en compte l'aptitude au service de ces systèmes, en vue d'assurer un comportement adéquat à long terme.

ZUSAMMENFASSUNG

In die Bemessung eines Tragwerkes muss unter bestimmten Umständen die Gebrauchstauglichkeit von Stahlbeton-Deckensystemen miteinbezogen werden. Dies ist der Fall bei hohem Dauerlastanteil, fehlender Durchlaufwirkung oder grossen Spannweiten. Bemessung und konstruktive Durchgestaltung müssen dann auf die Gebrauchstauglichkeit Rücksicht nehmen, um ein angemessenes Langzeitverhalten zu erzielen.

1. INTRODUCTION

Most reinforced concrete floor systems perform adequately. Such structures are usually designed for stress and then may be checked for serviceability. For most concrete floors systems, this procedure produces an adequate design. When reinforced concrete floor systems are subjected to moderate to heavy sustained loadings, contain long-spans, or are non-continuous, the serviceability design becomes a much more important factor in the adequate performance of the system. Under these criteria, when the serviceability portion of the design is overlooked and members are sized only on stress, excessive long-term deflection will occur. These excessive long-term deflections will adversely affect the performance of the structure. It is paramount that members be designed and detailed for serviceability to minimize excessive long-term deflections. Serviceability design should be given first priority under such criteria.

2. DISCUSSIONS

When analyzing and detailing reinforced concrete floor systems, special attention must be applied in certain portions of the structure to ensure adequate serviceability performance. From numerous investigations of existing, reinforced concrete floor systems exhibiting serviceability problems, certain parallels can be made with regard to sustained loadings, long-span members or lack of continuity in members, and excessive long-term deflections. The designer must be aware of these relationships so the serviceability requirements of the structure can be achieved. The additional cost for such design is minimal.

2.1 Sustained Loadings

The sustained, long-term loadings in some cases are obvious, such as in warehouses or libraries. In these cases, deflections are important. However, deflections are even more critical when the sustained loading is masonry partitions. In a normal classroom building, the partition weight can be substantial. Such partitions are very susceptible to cracking caused by deflections. Hence, the allowable deflection criteria becomes even stricter, with 10-mm maximum deflection or less required to avoid masonry cracking.

Sustained loadings affect the long-term, serviceability performance of a structure. Long-term, creep deflections can be two to three times the magnitude of the instantaneous deflections and will occur over several years.

Two case studies will be presented where excessive deflections were caused by sustained loadings. Under such circumstances, people occupying the building become concerned with the safety of the structure.

2.1.1 Case Study One

The first case study involves an addition to a library building. The original structure was built in 1961 with a 305-mm, flat plate slab having a minimum of three continuous spans in both directions. The reinforced, flat plate system has performed exceptionally supporting library shelving without noticeable deflections. In 1971, an addition with the same span lengths and superimposed loads was built, connecting to the original building. The slab was two-span continuous in one direction and contained more than three-span continuous in the other. The slab depth was reduced to 254 mm. No continuous top reinforcing was provided in either design. By 1977, the deflection in the addition's floors supporting the library stack shelving was an average of 50 mm. Additional deflection readings taken in 1980 showed an increase in deflections to an average of 65 mm. This additional deflection was due in part to an increase in load as the library collection expanded increasing the superimposed load. The additional load increased deflections and also contributed to an increase in the long-term, creep deflection. People occupying the building were concerned with the safety of the floors. Our stress analysis confirmed the slab capacity of the addition was adequate to support the imposed loading. The deflection analysis verified that the actual deflections were within 10 to 15 percent of the theoretical calculated deflections.

The main cause of the difference in performance of the two systems (original building vs. the addition) was the reduction of the slab thickness from 305 mm to 254 mm. The thinner slab did meet the American Concrete Institute's minimum slab-depth-to-span ratio, but actual deflections of the slab were not checked as part of the original design. No continuous, top, compression reinforcing was placed in the slab to minimize long-term deflection.

As part of our analysis, deflection calculations of the original 305-mm slab were compared to the 254-mm slab. The effective moment of interia for the original slab was 3 1/2 times greater, even though the difference in depth was only 51 mm. The increased loadings over time contributed to the continual deflections. Due to an anticipated increase in loadings, it was recommend that the building's use be changed.

A second minor contributing factor in the performance of the floor systems was the reduction from more than three continuous spans to only two spans. However, if the original slab thickness had been maintained, the deflections in the addition would still have been larger than the original building because of the two-span condition, but they would have been within acceptable limits.

2.1.2 Case Study Two

The second case study involves a college classroom building containing masonry partitions. The floor system consists of a 205-mm, reinforced concrete, flat plate spanning 7.3 m to reinforced concrete columns. Slab deflections average 64 mm causing substantial cracking of the masonry partitions. Our structural analysis of the existing conditions indicated that the slab was adequate to support the superimposed loadings, and that the excessive deflections were attributed to a lack of adequate stiffness in the structural system for the sustained, masonry partition loading. The deflection analysis confirmed the actual deflections were within 10 percent of the theoretical calculated deflection. The slab thickness did meet the American Concrete Institute's minimum slab-depth-to-span ratio. No continuous, top reinforcing was placed in the slab to minimize long-term, creep deflections.

In this case, the slab deflections were monitored over a period of several years. The use of the building remained the same with no increase in the sustained loadings. At the end of the monitoring period, slab deflections had subsided; so the masonry partitions could be repaired. It was recommended that the use of the building not be changed and no additional load be added or else the deflections would continue.

The deflection criteria for a slab carrying masonry partitions must be more stringent than a slab with no partitions.

2.2 Long Spans

Long spans can affect serviceability performance and must be designed with great care. What determines a long span is the system chosen for the area. But no matter what system is used and how light the loading is, deflections must be calculated when the depth-to- span ratio approaches the code depth-to-span limits.

2.2.1 Case Study Three

The third case study involves a college student union built in 1971. In the office space section of the structure, a 280-mm thick slab is used in a bay spanning 12.2 m by 10.9 m. Readings taken soon after the building was occupied in 1972 indicated a deflection of over 65 mm. By 1988, the deflection at midspan was in excess of 100 mm. Our analysis concluded that the slab lacked adequate stiffness to provide adequate, serviceability performance even though the slab did meet the American Concrete Institute's minimum thickness-to-span ratio.

There was no substantial, superimposed, live load and only minimal dead load of several metal stud partitions. The excessive deflections were caused by the long span. After monitoring the slab for several year, the ongoing deflection were continuing. The area was reinforced with steel beams and columns.

The use of a flat plate slab to span this area was the wrong choice of framing. A system of greater depth was required to adequately span this area. Our analysis indicated that either a waffle slab or a one-way, pan joist system would have limited the deflection to an acceptable magnitude. The building space could have accommodated such a system in this area.

2.3 Continuity in Structures

Continuity in a concrete floor system can enhance serviceability performance. If a system is designed for continuity, but if the actual boundary conditions do not provide continuity, serviceability performance will decrease.

2.3.1 Case Study Four

The fourth case study involves a three-story building containing a 205-mm thick, reinforced concrete, flat slab supported by reinforced concrete beams. In one direction, the slab spans three bays with each bay 7.9 m in length. In the other direction, there are two spans one of 7.9 m and the other of only 2.5 m. The slab deflections were greater than 50 mm. Our analysis indicated that the slab was designed as a continuous structure in both directions. But in reality, continuity was present in only one direction because the very short slab in the adjacent span did not provide full continuity. The slab did meet the American Concrete Institute's minimum thickness- to-span ratio, but the lack of continuity contributed to the excessive deflections.

After monitoring the structure for several years, it was determined that deflections had stopped. No corrective action was required. But it was recommended that no additional load be placed on the slab and the use not be changed.

The original design should have accounted for the lack of continuity in the one direction. The designer should ensure that the way the structure acts and his assumptions are compatible. Making the wrong assumption will invalidate all of the correct calculations that are made. In this case, the designer should have designed for a simple span; but he detailed for continuity. This would have minimized the excessive deflection problems encountered.

2.4 Corner and End Bays

Care must be taken when designing corner and end bays in continuous structures. Larger deflections can be expected in these areas if the span and loading are consistent with the rest of the structure. In Case Studies One and Two, 10 to 25 percent increased deflections were measured. In both case studies, the same depth framing system and spans were used as the rest of the building.

3. RECOMMENDATIONS

Do not use the code's minimum depth-to-span ratio nor stress analysis only to size members. Members must be sized on serviceability criteria. The designer must check the critical areas for initial and long-term deflections. The serviceability criteria may also be different depending on the use of the structure. A ln/360, live load, long-term deflection for a warehouse floor may be acceptable; where as in a floor with the same spans supporting masonry walls, it would not be acceptable. The long-term deflection would more likely be limited to ln/600 with a 10-mm limit.

When designing corner and end bays, try to use shorter spans and stiffer members. Under the same loading criteria, the deflection in these areas will be greater than the remainder of the floor. Deflections in these areas must be accounted for and should not be overlooked, even if the rest of the structure is adequate.

Use the most appropriate structural system. Do not use the same system used in the rest of building where in a critical area it would be marginal. The additional cost of changing the framing will be out weighted by the better performance of the structure.

Detail members for continuity; and in critical areas, try to use members with a minimum of three-span continuous. Where short spans are adjacent to long spans, design the longer spans to carry a greater portion of the load then by a continuous analysis; but still detail for continuity.

Detail the members for serviceability. Provide continuous, compression reinforcing to minimize long-term, creep deflections. Camber members for full, long-term, dead load deflections. Use members with sufficient depth to minimize deflections.

Specify construction practices that will minimize early loading of the structure. Use higher strength concrete to achieve design strength within 7 to 14 days. Specify additional floors to remain reshored, keeping a minimum of four floors to support the weight of the floor being placed. Deflections during construction will affect the performance of the structure where flat floors are required.

4. CONCLUSIONS

Under certain parameters, serviceability design of reinforced concrete floor systems becomes the most important aspect of design. If neglected, problems of excessive deflections will occur. Using the code's minimum depth-to-span ratio will not always result in a structure that will give adequate, serviceability performance. Deflections must be calculated on actual conditions of loading and continuity to ensure adequate long-term performance.

Detailing a structure for serviceability can also minimize problems. Providing adequate camber and continuous compression reinforcing will help prevent long-term, creep deflections from occurring. Construction practices are also very important in serviceability performance. Concrete strength must be achieved before construction loads are imposed on the system.

Questions of structural adequacy are raised when concrete floor systems do not meet expected serviceability performance. In some case, the lack of serviceability performance can affect use. The designer must be aware of the performance requirements for structural serviceability so that an adequate system is provided and allows the owner the flexibility to change the use of the structure if so desired.