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SYSTEMATIC REVIEW OF LONG-TERM BEHAVIOR IN COMPOSITE BEAMS

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ABSTRACT

Composite steel-concrete beams are an economical and efficient solution for building and bridge applications. However, In the analysis of structures, only the instantaneous deformation is often taken into account, but long-term loads can cause more significant deformations for the same applied load. This work concerns the effects of time-dependent concrete behavior, such as creep and shrinkage, which include service and ultimate limit states. So the general aim of this research was to evaluate the long-term flexural behavior and functioning of steel-concrete composite beams through a systematic literature review. It was possible to do a qualitative analysis of the increase of deflection and slip through time and effects in dispositions of strains in long-term loading. After that discussion, it was possible to deduce that long-term behavior can vary a lot in the characteristics of the short-term exceeding design code provisions. However, there is still a lack of data in experimental results for more detailed analysis.

KEYWORDS: Steel-concrete, Composite beams, Long-term behavior

REVISÃO SISTEMÁTICA DO COMPORTAMENTO DE LONGA DURAÇÃO EM VIGAS MISTAS

RESUMO

As vigas mistas aço-concreto são uma solução econômica e eficiente para aplicações em edifícios e pontes. No entanto, na análise de estruturas, muitas vezes apenas a deformação instantânea é levada em consideração, mas cargas de longa duração podem causar deformações mais significativas para uma mesma carga aplicada. Este trabalho trata dos efeitos do comportamento do concreto dependente do tempo, como fluência e retração, que afetam os estados limite de serviço e último. Assim, o objetivo geral desta pesquisa foi avaliar o comportamento à flexão a longo prazo e o funcionamento de vigas mistas aço-concreto por meio de uma revisão sistemática da literatura. Foi possível fazer uma análise qualitativa do aumento da deflexão e slip ao longo do tempo e efeitos nas disposições das deformações da seção transversal em carregamentos de longa duração. Após essa discussão, foi possível deduzir que o comportamento de longo prazo pode variar muito as características de curto prazo excedendo as disposições dos dispositivos normativos. No entanto, ainda faltam dados em resultados experimentais para uma análise mais detalhada..

Palavras chave: Aço-concreto, Vigas mistas, Comportamento de longa duração.

1 INTRODUCTION

All highlighted projects in the engineering field need to undergo an optimization process, addressing essential premises for engineers: (a) economy and (b) good performance (Leite & Pereira Júnior, 2019). The pioneers in incorporating combined steel and concrete elements in the construction industry were composite beams. Initially, the profiles were coated with non-structural concrete, aiming to reinforce the steel elements' resistance against the effects of fire. However, with the advantages gained, this technique is also employed to increase the beam's strength (Rossi *et al.*, 2022).

The presence of shear connectors provides the composite action; these are mostly welded to the upper flange of the steel beam and embedded in the concrete slab during concreting. This structural component is efficient when subjected to positive moments, leveraging the capacity of concrete and steel to perform well in compression and tension, respectively. This efficiency ensures the satisfaction of various limit states. This work addresses those affected by time-dependent concrete behavior, such as creep and shrinkage, including both serviceability and ultimate limit states.

In the analysis of structures, only the instantaneous deformation is often taken into account, but long-term loads can cause more significant deformations for the same applied load. Gilbert & Bradford (1995) studied the behavior of composite beams connected by studs. The results showed that the long-term strains reached between two and three times the value of the instantaneous strains under the same applied loads.

The serviceability of such structures is fundamentally affected by creep and cracking and their interaction, making the structure behavior prominently nonlinear. Recent publications have highlighted the effect of creep and shrinkage on the overall behavior of composite beams (Nguyen & Hjiaj, 2016).

While concerning the long-term behavior of such innovative composite beams, just a few studies are in the open literature despite extensive investigations on the time-dependent behavior of composite beams with conventional welded studs being undertaken (Bradford M.A. & Gilbert, 1992)(R I Gilbert, Bradford, Gholamhoseini, & Chang, 2012)(Mirza & Uy, 2010)(Nguyen, Hjiaj, & Uy, 2010)(Liu, Bradford, & Erkmen, 2013)(Ranzi, Leoni, & Zandonini, 2013).

It is challenging to know all the knowledge already published in a topic area with the constant growth of research and many articles published worldwide. A Systematic Review (SR) comes with a different approach from a traditional literature review. A well-executed SR is a rigorous and replicable approach to identifying, evaluating, and summarizing scientific evidence relevant to a clinical or policy question (EFSA, 2010).

In this context, the objective of this work was to seek relevant studies through search criteria in databases, inclusion criteria for the studies to select them, and criteria for evaluating the methodology and their results. With this, it is expected that it will be possible to seek evidence that can judge the behavior of steel-concrete composite beams when under the action of long-term loads.

2 METHODS

For the SR, the primary source of information was Scopus, officially named SciVerse Scopus, introduced by Elsevier Science in 2004. Web of Science and Scopus are the most comprehensive databases which are frequently used for searching the literature. However, Scopus covers a superior number of journals (Chadegani *et al.* 2013).

2.1 Review planning

Previously, four researchers were invited to contribute to the research protocol. This protocol specifies the process of identifying relevant searches. In this case, the research question was defined the search strategy and the criteria of exclusion. According to this SR's main objective and scope, the proposed research question was: *How is the long-term behavior of steel-concrete composite beams*?

2.2 Identification study

This process was initiated by building a comprehensive set of search terms related to the long term behaviour of composite structures. These were concatenated into a search string using Boolean' AND' and 'OR' operators. It applied a limit to the subject area and none for language or year of publication. All other search refinement options have not been changed. The Scopus® database was adopted using the strategy presented in Table 1.

Table 1 – Parameters used in the research

	Research
First field	*Time dependent OR long term OR creep OR shrinkage*
Operator	*AND*
Second field	*Steel* AND *concrete* AND *composite beam*

Thus, the research was carried out in December 2022. These citations were downloaded and exported to the reference manager Mendeley® for the selection of studies.

2.3 Article Selection, inclusion criteria definition, data extraction and synthesis

The selection process began by selecting potential relevant articles through a title and abstract scan of citations. After that, the citations that explicitly matched the exclusion criteria were excluded from the SR. The exclusion criteria, directly related to the research aim, were developed to describe the types of study eligible for an in-depth review. The exclusion criteria are listed in Table 2.

Table 2 - Exclusion criteria

No.	Criteria	Reason for exclusion
1	Just article and review as document types	Another type may not be relevant
2	*Qualis* - CAPES higher than or equal to B2 /or have JCR	a. Quality and Validity of research b. To reduce biased data synthesis
3	Full-text articles unavailable electronically	Resources and time are not available to gather them
4	Non-English language	It May not be relevant and widely disseminated academically
5	Do not address long-term experimental behavior from steel-concrete composite beams.	Steel concrete composite beam long-term behavior will be the focus in this work

The data extraction must be directly linked to the review question and the criteria to assess the eligibility of the studies. Within the SR, removing duplicate data is a common feature designed to improve reliability, increase accuracy, and validate data interpretation. Thus, the reviewers independently assessed each research presented in Table 1.

Table **1**. Each person extracted the data in a table of predefined evidence. Subsequently, the two tables were compared, and disagreements were resolved through discussion with the expert.

- Qualitative data collected from each article include:
- The main idea of the object of study application;
- Methodological procedures adopted in the experimental program;
- A complete description of the long term behavior of composite beams;

It should be emphasized that the data were categorized based on the similarity of studies, that is, to explore them in the search for consistent patterns or systematic relationships between variables.

2.4 Outcome measure

In this stage, the previously defined parameters regarding the Composite beam flexural tests performed by the respective selected works were qualitatively evaluated. In this way, it was assessed the evidence that deals with creep, shrinkage, and ductility parameters such as time-slip and time-deflection curves and cracking characteristics of the respective models. In this sense, were tried to synthesize the evidence to answer the desired scientific question presented in 2.1.

3 RESULTS AND DISCUSSION

The initial search without filtering the subject area to engineering recorded 262 studies in the database, but then, still in the database, with the subject area filter applied, it was recorded 247. In which with the research as described in Table 1.

Table 1. By title and abstract, 111 studies potentially relevant to the SR were selected. Therefore, those studies were evaluated according to the eligibility criteria. 6 articles, in the end, met the inclusion criteria and were added to the SR, to be analyzed carefully.

Additionally, the work from Bradford & Gilbert (1991) was included in this research. Even though it was not in the Scopus database, this work meets all the criteria in Table 4, and was cited for most of the works studied in this systematic review. Figure 1 presents the study search flow diagram, and Table 3 describes the results.

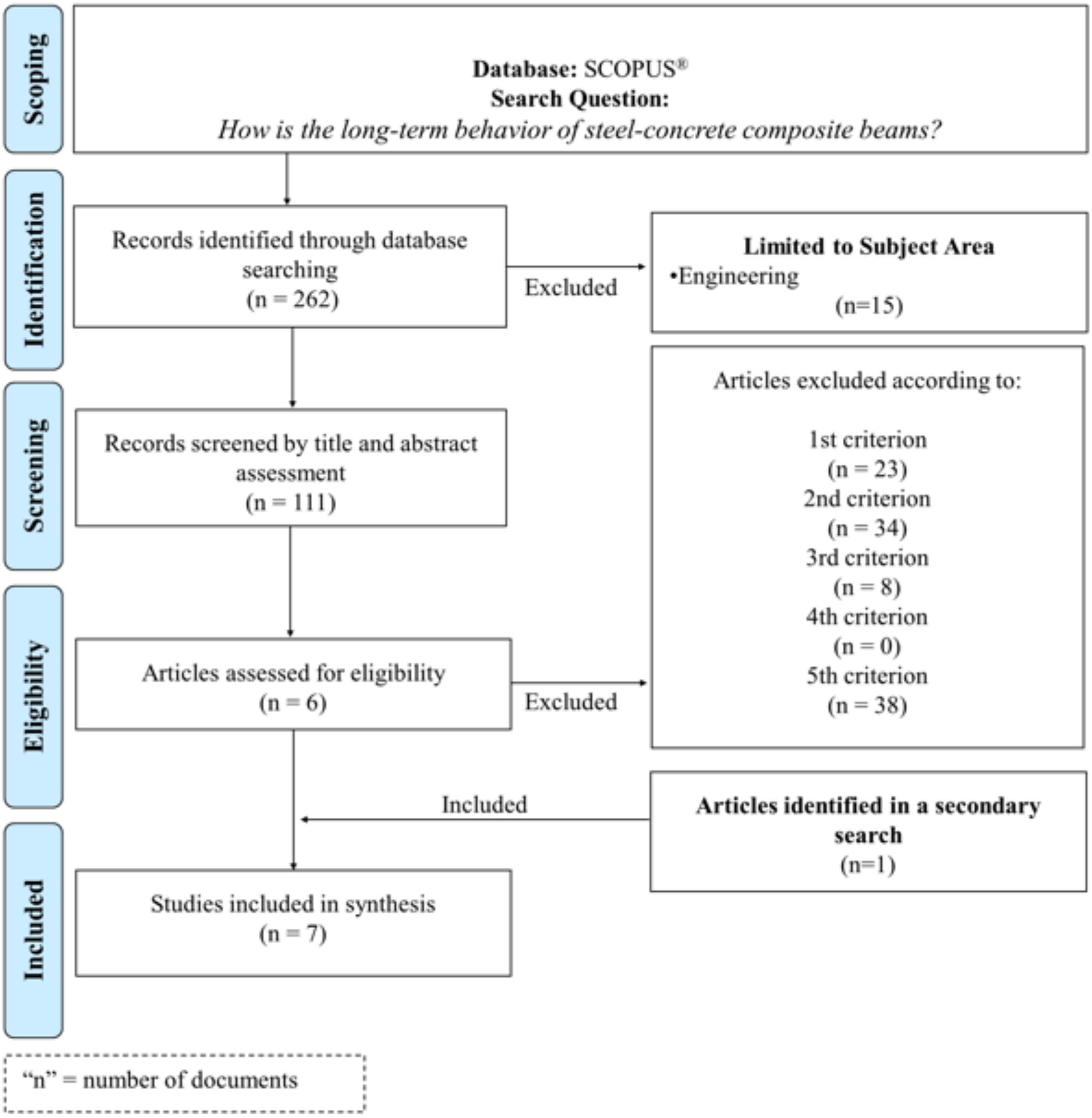

Figure 1. Flowchart of the systematic review process (PRISMA flow diagram).

Table 3 - Selected Studies

Citation	Title
Al-Deen *et al.* (2011a)	Full-scale long-term and ultimate experiments of simply-supported composite beams with steel deck
Al-Deen *et al.* (2011b)	Full-scale long-term experiments of simply supported composite beams with solid slabs
Al-Deen *et al.* (2012)	Long-term experiments of composite beams and connections
Ban *et al.* (2015)	Time-dependent behaviour of composite beams with blind bolts under sustained loads
Bradford & Gilbert (1991)	Time-dependent behaviour of simply supported steel-concrete composite beams
Fan *et al.* (2010)	Long-term behavior of composite beams under positive and negative bending. I: Experimental study
Xue *et al.* (2008)	Long-term behavior of prestressed composite beams at service loads for one year

3.1 Bibliometric analysis

It is essential to see the bibliometric indicators in the subject since it helps to measure indices of production and dissemination of knowledge that follow the scientific discipline's development, as well as the standards of authorship, publication, and use of research results.

Figure 2 shows the annual distribution of included studies from 1995 to 2015. The research was done without a paper publication date limit. After the exclusion criteria, there was only one paper in 1995, and there was a gap in the research, with papers only after 2008. That indicates that even though this subject was studied before, there is still some research.

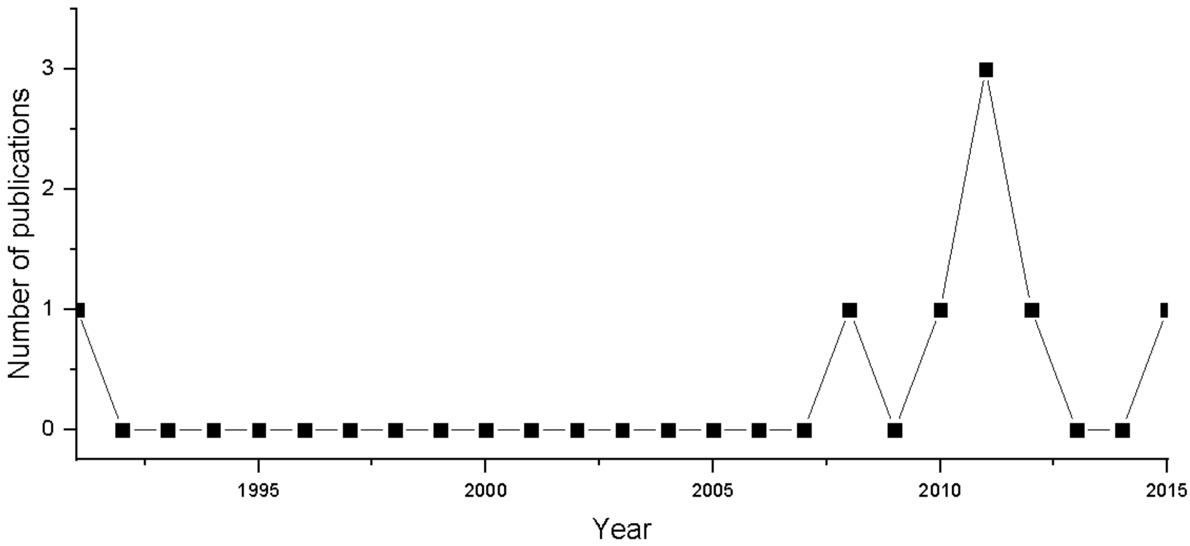

Figure 2 - Annual distribution of publications.

Table 7 presents information about the relevance and distribution of the journals in which the works are published. Of the 3 magazines collected, the Journal of Constructional Steel Research stood out with 3 works (42,8%). The others all presented only two papers composing this review.

Regarding the evaluation parameters of the journals, there is a significant academic relevance of the journals collected, with an average Journal Impact Factor (JIF) of 1.19 and Scimago Journal Rank (SJR) of 0.853. Among these journals, as seen in Table 4, the Journal of Constructional Steel Research had a majority in the two ranks simultaneously.

It is possible to observe the presence of publications in only 3 countries, the Netherlands, the United States, and the United Kingdom. Although the reference to places of publication in some cases differs from the places where the studies were carried out. This result illustrates a reference on the part of those who publish, thus indicating countries that are more welcoming to such technologies and, therefore, more developed.

Table 4 – Journals covered.

#	Journal	Quantity	Freq. (%)	SJR (2021)	JIF (2021)	country of publication
1	**Journal of Constructional Steel Research (JCSR)**	3	42,8	1.388	3.646	Netherlands
2	**Journal of Structural Engineering (JSE)**	2	28,6	1.385	3.312	United States
3	**Magazine of Concrete Research (MCR)**	2	28,6	0.797	2.46	United Kingdom
	Total/Mean	7	100	1.190	3.139	

3.2 Study characterization

Table 5 presents an overview of the selected studies in this systematic review. Concerning the studied stress, all the papers studied sagging moment, which is the most common way to design composite beams. However, composite beams can also be subjected to a hogging moment when they are close to beam-column joints or built as continuous elements. Even though it is not the most efficient setup for steel-concrete composite beams since the concrete will be subjected to tensile stresses.

In order to account for the situations where those composite structures are subjected to hogging moment, Al-Deen *et al.* (2012) and Fan *et al.* (2010) studied this type of stress in their works. Additionally, Xue *et al.* (2008) studied pre-stressed composite beams to provide data about the relaxation of the tendons.

Nowadays, there is many shear connector types, but all the studies used stud-type connectors for the shear connection in the composite beams. Only in Ban *et al.* (2015), it was also used two other types of blind bolt connectors and a concrete slab and steel beam without a shear connector. That could be because of the difficulty of executing long-term works. It is preferred to use the most common type of shear connector.

Regarding the type of slab studied in the works, almost all works used solid slabs. Only in Al-Deen *et al.* (2011a), it was used steel deck slabs. Solid slabs are easier to predict since their geometry is the same longitudinally, but with the outcome of more efficient types of concrete slabs, more work is needed to study other slab models.

For the type of construction, it was separated here in this work: Unpropped and Propped construction. Al-Deen *et al.* (2011a) only studied Unpropped Construction, Al-Deen *et al.* (2011b) and Ban *et al.* (2015) studied the two types and the rest of the articles used Propped Construction. Unpropped construction may increase the steel profiles, but it can reduce construction time. For the long-term behavior, The use of unpropped construction enables the self-weight of the concrete to be carried out by the steel joist at the time of the pour, therefore avoiding the creep in the concrete due to this dead load (Al-Deen *et al.*, 2011).

For the concrete strength, the average concrete strength of 29,06 MPa with a standard deviation of 3,67 MPa. So, none of the works used high-strength concrete, which would increase the difficulty of achieving higher deformation since the load would have to be higher because it is challenging to maintain higher loads for long-term tests.

Regarding the connector yield strength, the stud-type connectors had an average strength of 396,8 MPa; for the blind-bolt type, it was 852,2 MPa. Compared with the steel beam strength, which had an average strength of 330,6 MPa, the values of the stud connectors are close, but the blind-bolt types surpassed by more than 400 MPa the strength of the steel beam.

In order to evaluate the long-term tests, the works observed the deflections in the composite beams over time. For that, some beams only were subjected to their self-weight, and for others, external loading was added. All the works presented external loading in their research. However, Al-Deen *et al.* (2011a), Al-Deen *et al.* (2011b), Al-Deen *et al.* (2012), and Bradford & Gilbert (1991) add specimens only subjected to self-weight.

Regarding the degree of connection in the composite slabs, not all works displayed the degree used. However, it varied from 0,46 to 1, and the latter would represent a full shear connection. That could provide us with the long-term behavior of different shear connections.

The loading time is one of the most important parameters when studying long-term behavior because it will provide accurate data on how the section will behave over time. Most of the works presented a loading time of less than one year. However, Fan *et al.* (2010) studied the behavior of composite beams for almost three years, which will provide a better result to predict the deflection for more extended periods of time.

As a methodological strategy, all studies presented some variation in the experimental setup in some way. However, all had composite beams subjected to long-term loads, as were previously in the exclusion criteria. To better understand the layout variations and the paper's primary objective, Table 6 shows the methodology's main characteristics and the number of models used in the research.

Concerning the parameters analyzed in the studies, a non-uniform behavior can be seen concerning the studies insofar as each study has a different methodological approach to the subject, thus having the analysis of different parameters. However, despite the different approaches, many parameters are present in several works, reflecting the main parameters related to the long-term behavior of composite beams. Table 7 shows the assessed parameters in those studies.

Table 5. Overview of included studies.

Ref.	Studied Stress	Connector type	Slab Type	Type of Construction	Concrete strength (MPa)	Connector Yield stength (MPa)	Steel Beam strength (MPa)	Loading type	Degree of connection	Loading Time (Days)
Al-Deen *et al.* (2011a)	SM	Stud	SD	UP	26.1	351.6	326.98	SW and EL	0.79	134
Al-Deen *et al.* (2011b)	SM	Stud	SS	UP and PP	27.7	351.6	324.27	SW and EL	0.5	222 and 461
Al-Deen *et al.* (2012)	SM and HM	Stud	SS	PP	27.65	351.6	323	SW and EL	0.93 and 0.46	130
Ban *et al.* (2015)	SM	BB[1], Stud[2] and NC	SS	UP and PP	34.4	852.2[1] and 394.4[2]	404.85	EL	NI	251
Bradford & Gilbert (1991)	SM	Stud	SS	PP	31.1	NI	NI	SW and EL	NI	250
Fan *et al.* (2010)	SM and HM	Stud	SS	PP	24.5 and 34.0	NI	303.6	EL	1	1085
Xue *et al.* (2008)	PSD and SM	Stud	SS	PP	27.1	400.0	301	EL and PSD	NI	360

Notes:

SM	Sagging Moment	SS	Solid Slab
HM	Hogging Moment	UP	Unpropped
PSD	Prestressed	PP	Propped
BB	Blind-Bolt	NI	Not Informed
NC	Non-conector	SW	Self-Weight

SD	Steel Deck	EL	External Loading

Table 6. Main characteristics of methodology.

Ref.	Setup description	Justification	Number of Models
Al-Deen *et al.* (2011a)	Long-term test of Full-scale simply-supported composite steel-concrete beams connected by studs subject to self-weight and sustained load.	To investigate their long-term behavior and how this affects their ultimate response and provide benchmarking data for the numerical modeling	2
Al-Deen *et al.* (2011b)	Long-term test of Full-scale simply-supported composite steel-concrete beams connected by studs subject to self-weight and sustained load.	To compare the long-term behavior of these beams concerning pouring and loading conditions	3
Al-Deen *et al.* (2012)	Long-term tests of composite beams connected utilizing a web side plate with stud shear connectors subjected to hogging moment and continuous beams.	To evaluate the serviceability limit state of such joints regarding their time-dependent behavior	6
Ban *et al.* (2015)	Long-term test of Full-scale simply-supported composite steel-concrete beams connected by blind bolts and stud shear connectors subject to sustained load.	To analyze the time-dependent behaviour of composite beams with blind bolts subjected to sustained loads.	4
Bradford & Gilbert (1991)	Long-term test of Full-scale simply-supported composite steel-concrete beams connected by studs subject to self-weight and sustained load.	To provide benchmark data for calibrating more complex theoretical treatments incorporating creep, shrinkage, and connector slip.	4
Fan *et al.* (2010)	Long-term tests of Simply supported and continuous composite beams connected by stud shear connectors subjected to an external load.	To examine the long-term behavior of composite steel-concrete beams under sustained loads.	4
Xue *et al.* (2008)	Long-term tests of prestressed and nonprestressed composite beams connected by stud shear connectors subjected to an external load.	To examine the long-term behavior of prestressed composite beams under sustained load conditions for one year.	3

3.1 Discussion

Even though the studies with composites beam reviewed in this work show considerable differences between materials properties, spans, the structure's geometry, type of loading, etc., this part will discuss some of the principal characteristics of the analyzed works.

3.1.1 Ultimate test strength

The focus in this work is the long-term behavior, but in Al-Deen *et al.* (2011a), the composite beam is also submitted to a short-term test to see if its ultimate strength had suffered any decrease because of the long-term test that was aplite to it.

In Al-Deen *et al.* (2011a), The ultimate flexural capacity of the beam observed from the experiment was well higher than the expected ultimate flexural capacity. Based on these results, it could be concluded that the ultimate response was not affected by time effects for the geometric and material range considered in this study.

Table 7. Assessed Parameters

Ref.	Shrinkage	Creep	Analytical model	Numerical Model	Temperature	Humidity	Cracking	Push-outs	Short-term tests	Design review	Code review	Ultimate response	Assessed parameters
Al-Deen *et al.* (2011a)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓	Non-uniform shrinkage; Self-weight vs. External Load; Profiled sheeting
Al-Deen *et al.* (2011b)	✓	✓		✓	✓	✓		✓		✓			Self-weight vs. External Load; Um-propped vs. propped construction
Al-Deen *et al.* (2012)	✓	✓			✓	✓	✓	✓		✓			Load configuration; Steel beam joint
Ban *et al.* (2015)	✓	✓		✓	✓	✓		✓		✓			Different types of shear connectors; un-propped vs. propped
Bradford & Gilbert (1991)	✓	✓						✓		✓			Self-weight vs. External Load; Different Stud intervals
Fan *et al.* (2010)	✓				✓	✓	✓	✓		✓	✓		Different stresses; Different concrete strength; Cracking
Xue *et al.* (2008)			✓							✓	✓		relaxation of prestressing tendons
	86%	71%	29%	43%	71%	71%	43%	86%	14%	100%	29%	14%	

However, it should be noted that the load applied in the long-term test was just 14% of the ultimate flexural capacity in the ultimate test. Because of that, other studies should try another percentage of strength to determine how higher long-term loads could affect the behavior of composite beams.

3.1.2 Deflection x time curves

It should be noted that creep and shrinkage are two main factors that influence the behavior of composite beams submitted to long-term beams. The shrinkage will work differently in positive and negative moments; in the positive moment, it will go along with the concrete's compression, diminishing the concrete's length. However, in the negative moment, the stresses will cause tension in the concrete, but the shrinkage will cause stresses in the opposite direction. That way, the deflection may also diminish through time.

Because of their behavior differences, we will separate topics from the beams submitted to positive and negative moments.

- Composite beams submitted to positive moments.

In all selected works for this research, the general trend is a high rate of deflection increase for the early period after loading, followed by a more gradual rate of deflection increase. In almost all studies, except for Fan *et al.* (2010) and Xue *et al.* (2008), there was none or almost no decrease in deflection throughout the test.

In Fan *et al.* (2010), the deflections of the composite beams had a more gradual increase in the first four months after loading, reaching its first deflection peak during that time, then fluctuating due to the variation of environmental conditions. It can be explained by the fact that the creep and shrinkage of concrete developed almost entirely during the first four months. For the rest of the test, a high correlation was observed: the progressive deflection decrease was accompanied by the progressive increase in temperature and/or moisture, and the inverse was also true.

The work of Xue *et al.* (2008) did not provide information about temperature or moisture, so it was impossible to evaluate the influence of those parameters in the decrease in deflection at the earlier period of the test. However, the rapid relaxation of the prestressed tendons could have caused that because it was not observed decrease in the deflection for the non-prestressed composite beam tested.

One essential data about the deflection x time curves is the maximum deflection acquired by the specimens by creep and shrinkage and the relationship between it and the instantaneous deflection. Figure 3 shows the ratio of long-term deflection and instantaneous deflection (δ_{lt}/δ_i). The specimens are divided by the selected works and the type of loading.

In Figure 3, it is possible to see that the increase in deflection had a significant variation throughout the test, that at least there was an increase in the deflection by 23% by long-term factors. Also, these values depend on the value of the instantaneous deflection. For example, in Bradford & Gilbert (1991), the increase in deflection for absolute value was higher for the beams subjected to external loading than when subjected only to self-weight. However, since the deformation from the self-weight was a lot smaller, the relation δ_{lt}/δ_i was higher for for the latter ones. For that, different values of percentage of the ultimate strength of the composite beams may cause very different values for δ_{lt}/δ_i.

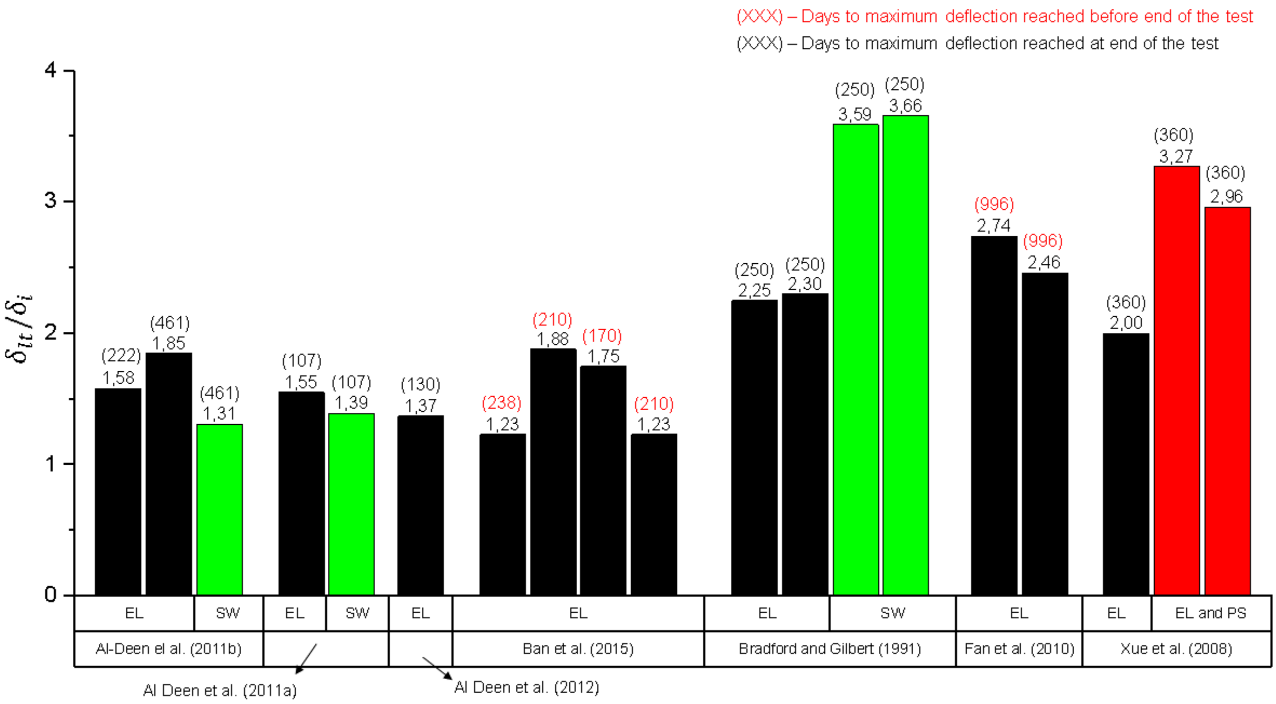

Figure 3 - Ratio of long-term deflection and instantaneous deflection (δ_{lt}/δ_i) of selected studies.

Also, in Figure 3 for Xue *et al.* (2008), it is possible to see that prestressed beams have a higher increase in deflection than non-prestressed ones, which can be explained by the fact that besides the creep and shrinkage, there is also the effect of the prestressing tendons relaxation.

Also, the number of testing days would impact the deflection results, with tests lasting up to 1085 days. Most of the selected works showed maximum deflection at the end of the test, showing that it could increase deflection with more time.

Figure 4 summarizes the multiplier of instantaneous deflection by a boxplot. Eurocode 4 (2004) for prestressed and nonprestressed composite beams have ratios of long-term-to-instantaneous deflections of 1.5 and 1.4 for one year, respectively. Furthermore, according to the Chinese code GB50017-2017, prestressed and nonprestressed composite beams have ratios of long-term-to-instantaneous deflection of 1.3 and 1.2 for one year, respectively.

ABNT NBR 8800:2008 does not mention differences in effects in prestressed and nonprestressed composite beams. However, it says that to consider long-term effects, it may simply multiply the short-term deflection by 3.

With that, the Chinese code GB50017-2017 and Eurocode 4 (2004) do not cover half of the results presented in this systematic review. However, the ABNT NBR 8800:2008 covers more than 75% of the results of the increase in deflection. So as all the codes presented here do not cover all results in this systematic review, they should be reviewed to compute higher δ_{lt}/δ_i.

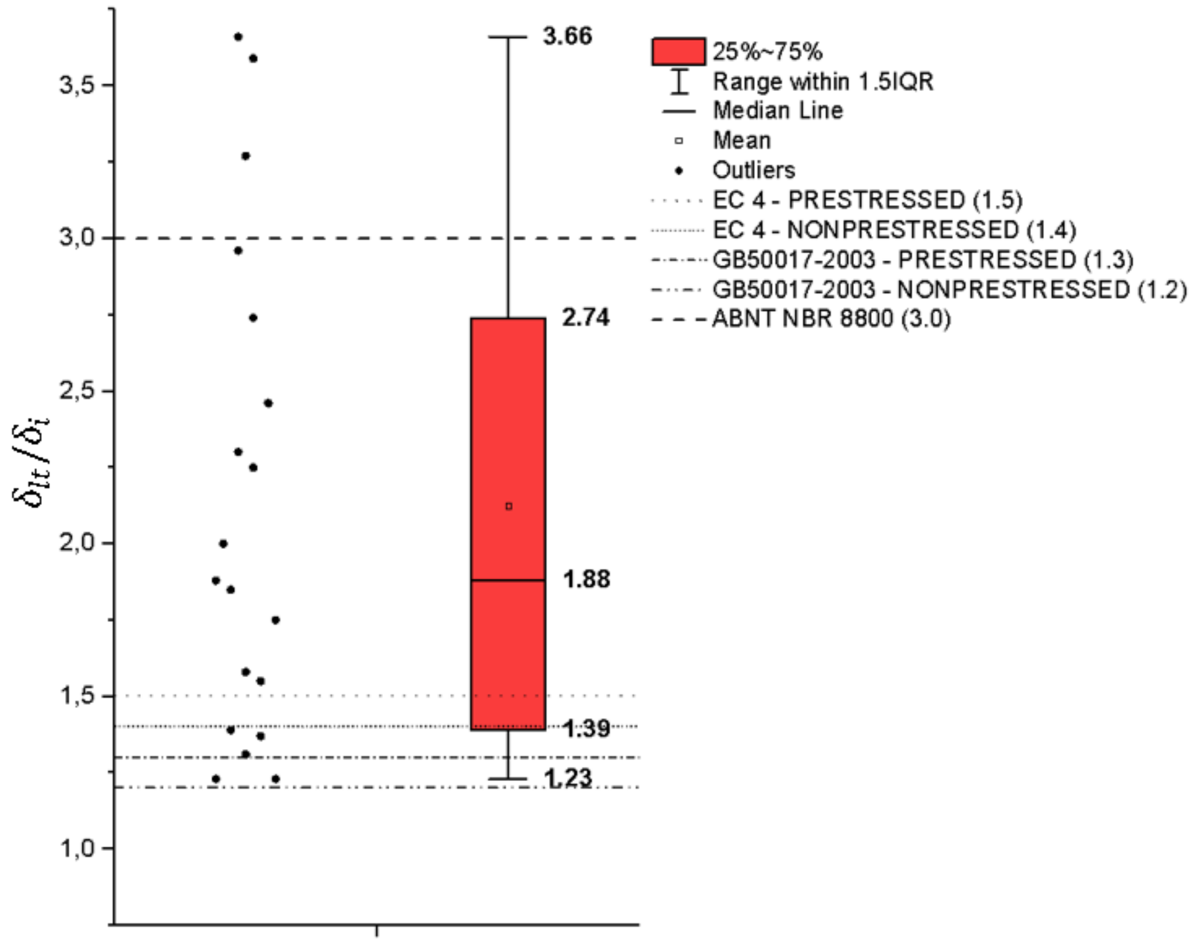

Figure 4 - Boxplot of long-term deflection and instantaneous deflection (δ_{lt}/δ_i) of selected studies in comparison with design codes.

- Composite beams submitted to positive moments.

Only in the works of Al-Deen *et al.* (2012) and Fan *et al.* (2010) had specimens submitted to hogging moment. For those cases, the variations in deflections observed after the day of loading remained small in comparison to the magnitude of the instantaneous displacements (Figure 5) compared to the composite beams subjected to positive moment, which could be explained since the shrinkage was acting in the opposite directions of creep.

In Al-Deen *et al.* (2012), even the specimens submitted to a higher load to induce pronounced cracking did not significantly differ in the deflection increase, and there were no new concrete cracks over time. The length of the existing cracks did not vary with time. In that study, there was also a difference in the degree of connection by different shear connector spacing, but that did not cause a significant deflection variation either.

Fan *et al.* (2010) monitored a rapid decrease in deflection during the early loading period, which can be explained by tension stress in the concrete slab during concrete shrinkage. After 80 days, cracks began to occur in the concrete slab in the negative bending region. They interrupted the decrease in deflection, resulting in a breakpoint in the deflection curve at 80 days of loading.

After 200 days, deflection fluctuated, but it was mainly due to the variation in temperature and humidity.

In the same study, The comparison between the tested deflection and the calculated deflection by Eurocode 4 (2004) showed that the effective modulus method is accurate for calculating the instantaneous deflection. However, it is not accurate to calculate the long-term deflection, especially for composite beams under negative bending moments.

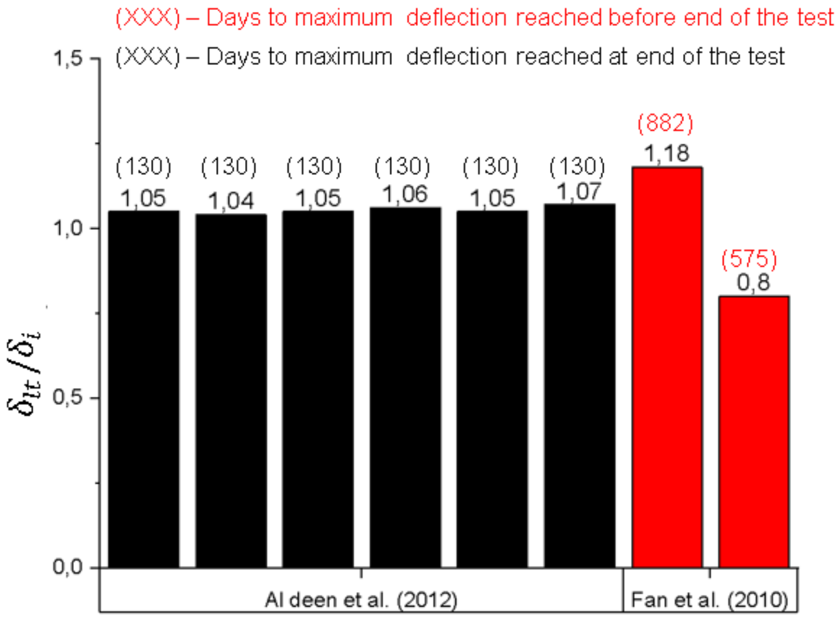

Figure 5 - Boxplot of long-term deflection and instantaneous deflection (δ_{lt}/δ_i) of selected studies in comparison with design codes –negative moment.

3.1.3 Slip vs time curves

For the slip, it can be seen in the selected works that the long-term response will depend on which one will have more substantial effects, shrinkage or creep. In Al-Deen *et al.* (2011a) it is possible to see the difference of beams subjected to positive moments by only the self-weight or external loading. When it is only the self-weight, the shrinkage affects the long-term behavior, so the concrete slab tends to slip inwards, which is considered a negative slip in this work. However, when external loading is added, the creep will govern the long-term behavior, but sometimes it cannot surpass the shrinkage, and the long-term slip, tends to be close to zero. It is possible to confirm this behavior in Al-Deen *et al.* (2011b), Al-Deen *et al.* (2012), and Bradford & Gilbert (1991).

Only Al-Deen *et al.* (2012) presented slips for composite beams subjected to negative moments. Similarly, to the deflection measurements, long-term slip values were smaller than the instantaneous ones.

3.1.4 Strains

Only in the works of Al-Deen *et al.* (2011a), Al-Deen *et al.* (2011b), Al-Deen *et al.* (2012), Bradford & Gilbert (1991), and Fan *et al.* (2010) had measurements of strain. When the beams were subjected to positive moments, all studies presented the same behavior, the change in the neutral axis of the specimens moving downwards. So depending on where the composite section's neutral axis was situated, the strains of steel or concrete may change from tensile to compressive.

The only work that showed measurements of strains in composite beams subjected to negative moments was Fan *et al.* (2010). For this work, during the first 50 days, the strains of concrete and reinforcements decreased gradually because of the concrete shrinkage. However, concrete cracking incurred an abrupt increase in the concrete strain, resulting in a sudden decrease in the steel strain in the compression flange. So to prevent significant changes in strain, more reinforcement should be provided to reduce concrete cracking.

4 CONCLUSIONS

In this study, a systematic review was performed to propose a new discussion about the long-term behavior of steel-concrete composite beams. Even though many studies about composite structures exist, only a few have experimental data to provide accurate data for more extensive analysis, probably due to long-term tests' high cost and complexity. With that, only 7 were selected by the exclusion criteria.

For this, a bibliometric analysis of the studies was performed to identify the main ideas of the application of the connectors and the methodological strategies the authors used. Further, several characteristics observed in the selected works were qualitatively discussed. Thus, it has as conclusions:

Long-term loads may not alter the load-carrying capacity of the composite member for the geometric and material range considered in this study.

For beams subjected to positive moments, In all selected works for this research, the general trend is a high deflection increase for the early period after loading, followed by a more gradual rate of deflection increase. Nevertheless, for composite beams subjected to negative moments, variations in deflections observed after the day of loading remained small compared to the composite beams subjected to positive moments, which that shrinkage could explain was acting in the opposite directions of creep when hogging moment is applied.

When subjected to long-term loads, the neutral axis of the specimens moves downwards in composite beams submitted to positive moments.

According to the selected works, The multiplier of instantaneous deflection provided by Chinese code GB50017-2017, Eurocode 4 (2004), and ABNT NBR 8800:2008 do not cover all the results presented in this systematic review. So here, it is proposed to obtain the long-term vertical deflections for one year of nonprestressed composite beams by using 3.66 as the multiplier of instantaneous deflection, and 3.26 for prestressed composite beams.

Further experimental work is required to validate the geometric and material range and different ratios between ultimate strength and long-term loads. Since most of the works only used a small fraction of the ultimate strength of composite beams.

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