



## **Towards establishing the reuse design rules for cold-formed steel channel stub columns**

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### **Abstract**

This study systematically investigates the reusability of cold-formed steel (CFS) stub columns experiencing local buckling. A series of eight cyclic loading tests, including an initial assessment and a final test after accelerated corrosion simulating ten years of service, were performed on CFS channel columns with varying slenderness, thicknesses, and embossments but consistent length and fixed ends. The experimental program encompassed 231 individual tests on 24 specimens, comprising 192 reuse cycles and 39 post-corrosion evaluations. Detailed analyses of structural stiffness and strength at each cycle enabled determination of the reuse resistance factor ( $\phi_R$ ) and prediction of reusable strength ( $P_{n-R}$ ) over successive applications. The results establish reuse thresholds for load levels and permissible numbers of cycles. Key design recommendations include limiting reuse for sections thinner than 0.5 mm with normalized slenderness above 6.27, enabling up to two additional reuses for sections 1 mm or thicker with slenderness between 2.16 and 3.21, and providing a new empirical model for  $\phi_R$ . Reusable strength is shown to be reliably estimated from original material properties. These findings contribute robust experimental evidence and guidance for sustainable reuse of CFS columns in structural engineering practice.

### **1. Introduction - Why prioritize the direct reuse of steel structures over recycling?**

Developments in renewable energy technologies are advancing rapidly to replace fossil fuels in pursuit of achieving global net-zero emissions by mid-century. Comparable progress is urgently needed within the construction sector, which is responsible for a substantial portion of global carbon emissions—approximately 21% arising from material production and processing—and accounts for over 59% of total natural resource extraction, including metals, sand, gravel, crushed rock, and other non-metallic minerals [1-2]. To mitigate the persistent environmental impact of construction, several policy initiatives have been introduced. Among these, a key strategy is the promotion of Circularity in Construction, which emphasizes the “recycling” and “direct reuse” of construction materials to extend their service lives [3-7].

According to ISO 20887 [8], recycling is defined as the “ability of components, materials or both to be separated and reprocessed for use as input materials in the same or different functions,”

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whereas reusability refers to the “ability of a product, component or system to be used in its original form multiple times while maintaining its value and functional qualities.” Despite recognition of recycling’s importance since as early as 1966 [9], it remains an energy-intensive process in the construction industry. In contrast, direct reuse typically requires far less energy, as it avoids reprocessing. For instance, producing 1,000 kg of recycled steel demands 710 kg of scrap steel and 2.3 GJ of electricity, in addition to substantial inputs of iron ore, coal, and limestone [10]. Therefore, wherever feasible, direct reuse should be prioritized over recycling to achieve greater environmental efficiency. The practical realization of direct reuse in structural engineering requires new design methodologies and fundamental shifts in construction practices. Structural members must be connected through demountable joints rather than traditional monolithic ones [4-6, 11-20], and both design and construction processes must align with reuse-oriented principles. Two central design development needs are identified to support circularity in construction [21-27]:

- (i) Design for direct reuse of components-developing new structural elements intentionally designed for future reuse with appropriate design reductions; and
- (ii) Design of used components for direct reuse-developing methods to assess and prepare existing elements, originally intended for single use, for safe future applications.

The first is conceptually more straightforward, involving purpose-designed new components with controlled design margins. The second, however, is more complex, requiring detailed assessments of structural integrity, past loading history, deformation, and deterioration. In both cases, the formulation of reuse design rules must consider material properties, geometry, fabrication and erection methods, applicable design codes, service age and conditions, and current component state (e.g., corrosion, damage, or plastification). As the field evolves, additional considerations such as environmental exposure, connection types, and structural configurations will further inform design refinements. Establishing design rules for reuse begins with evaluating the feasibility of reuse-determining how much structural capacity remains after dismantling a member. Once the residual load-bearing capacity is quantified, a reuse resistance factor ( $\phi_R$ ) can be developed to define its reusable strength ( $P_{n-R} = \phi_R \times P_n$ ). This study investigates the reuse behaviour of cold-formed steel (CFS) columns subjected to local buckling, with three primary objectives:

**Feasibility of reuse** - Assessing the reusability of CFS columns under pure local buckling.

**Design for reuse** - Developing a reuse resistance factor ( $\phi_R$ ) to evaluate reusable strength for multiple cycles of use, supplementing conventional design factors ( $\phi_c$ ).

**Long-term use validation** - Simulating 10 years of corrosion through accelerated testing to evaluate long-term reuse behaviour based on  $\phi_R$ .

While numerous prior studies have examined the structural performance of CFS channel sections under local buckling [28-46], this research provides the first systematic assessment of their reuse potential within a circular design framework. There are also several international projects related to construction reuse (see reference [47] for details of the projects), those projects are primarily focused on hot-rolled steel structures, leaving CFS reuse largely unexplored. Moreover, this research will be an addition to the existing design standard SCI P427 [48] and PROGRESS [49].

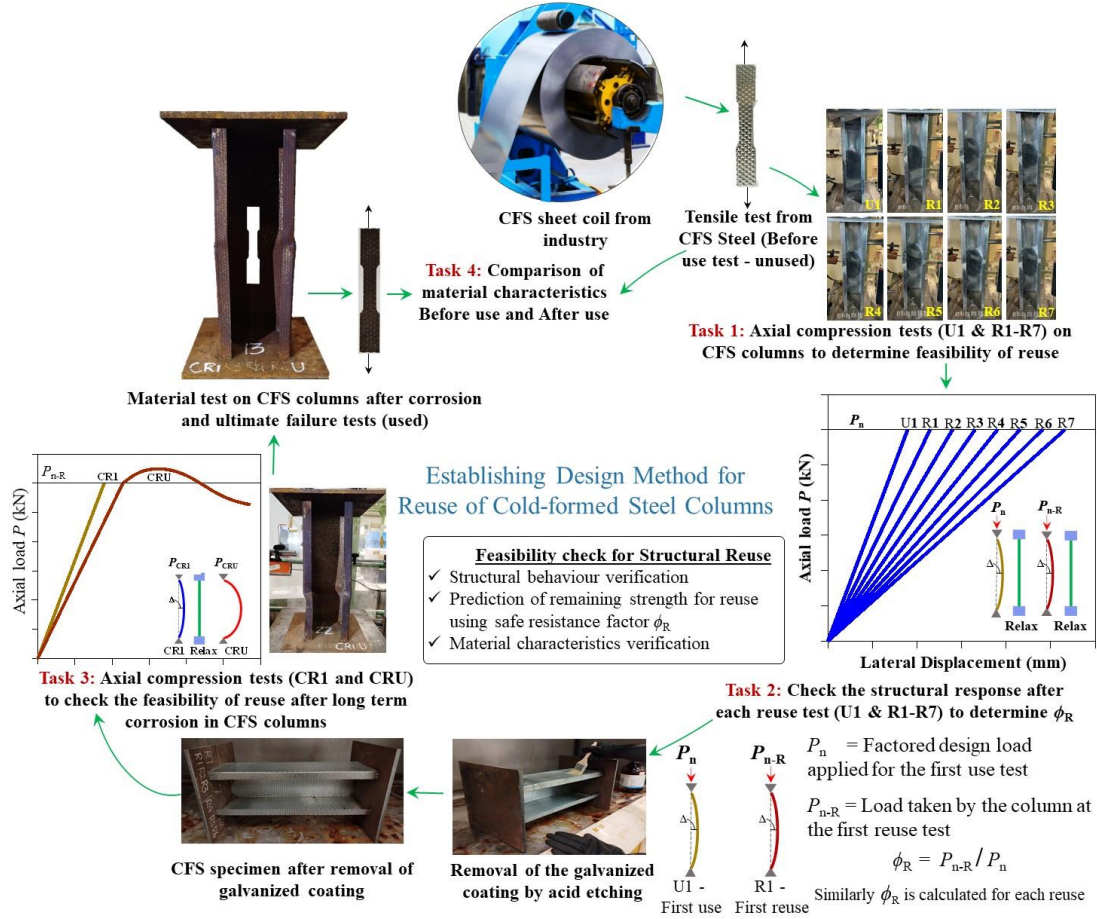


Figure 1: Concept of Direct Reuse for Achieving Circular Economy in Construction [3]; tasks for establishing a reuse design approach.

The research methodology (illustrated in Fig. 1) follows four main tasks. Task 1 examines reuse feasibility through repeated load testing up to the member’s design load ( $P_n$ ) until stiffness degradation is observed. Task 2 determines  $\phi_R$  based on stiffness and strength degradation from repeated loading cycles. Task 3 subjects previously tested columns to accelerated corrosion equivalent to 10 years of exposure before applying additional reuse cycles under predicted reuse loads ( $P_{n-R}$ ). Finally, Task 4 compares material properties before and after testing using tensile strength analysis to identify any degradation, which is then incorporated into a material reuse safety factor for design adjustment. Upon completing these stages, this research establishes design guidelines for both “design for direct reuse of components” and “design of used components for direct reuse,” specifically for CFS structural members, contributing a foundational step toward implementing circular construction principles.

Table 1: Geometric and design properties of the considered CFS channel sections

thickness ( $t$ ) (mm)	$t_b$ (mm)	$\lambda_1$ Slenderness	$A$ (mm <sup>2</sup> )	$f_y$ (MPa)	$E$ (GPa)	$f_{cr1}$ (MPa)	$P_y$ (kN)	$P_{cr1}$ (kN)
0.5	0.475	6.27	233.9	301.15	205.28	7.8	71.37	1.82
1.0	0.97	3.21	470.0	334.52	202.37	32.5	157.21	15.26
1.5	1.47	2.16	700.4	348.12	199.02	74.9	243.83	52.44

Note: Data presented correspond to the plain steel channel columns [See reference 47 for details]

## 2. Description of CFS Channel Members and Repeated Compression Testing Procedures

The compression strength testing programme comprised a total of 24 specimens, arranged as 12 pairs of identical specimens. All specimens had a uniform length of 450 mm and a consistent cross-section, as illustrated in Figure 2. The 12 specimen pairs encompassed three different thicknesses ( $t=0.5, 1.0$  mm, and  $1.5$  mm) and four embossment configurations, including three embossed patterns and one conventional plain steel sheet. For each thickness, the embossment types were classified as (i) small, (ii) medium, and (iii) large. The embossment thicknesses ( $t_e$ ) and the corresponding surface patterns are available in [47]. The geometric dimensions and mechanical properties of the CFS channel-section columns are summarised in Table 1. More details of specimens and repeated testing procedures are available in [47]. The design strength  $P_n$  of the CFS channel columns tested are determined according to AISI S100 [50]. The geometric imperfection is measured according to Selvaraj and Madhavan [51]. This testing procedure is similar to the ones used by other researchers [52-61] except reuse protocol established in [3-6,47 and 62].

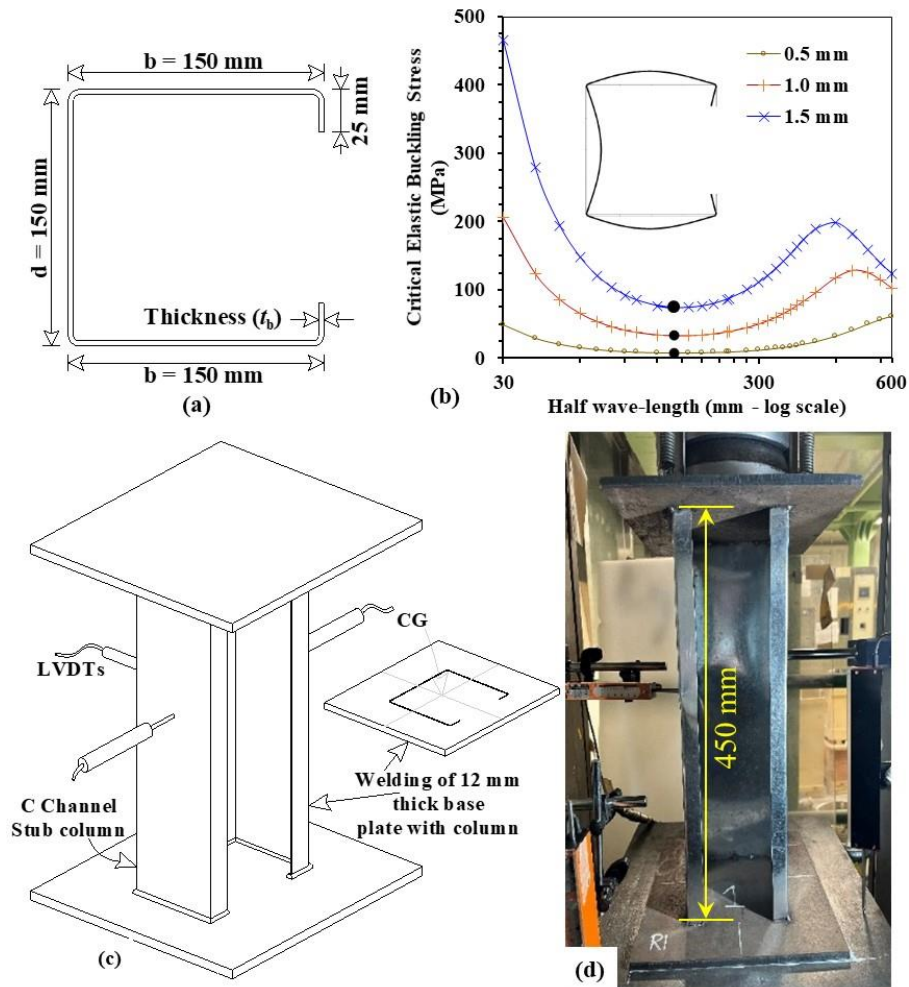


Figure 2: CFS Plain and embossed column properties and testing method: (a) outer dimensions of CFS channels; (b) buckling curves of CFS channels with different thicknesses; (c-d) CFS columns welding to base plate and axial load testing method for fixed-ended columns

### 3. Results and Observations - Reuse of Steel Channel columns

This section addresses Task 1 - Feasibility of Reuse by presenting and discussing the results and key observations from the reuse tests. The axial load–axial displacement and lateral displacement responses of the cold-formed steel (CFS) short columns obtained from each reuse test (U1 and R1-R7) are illustrated in Figure 3 (it is a sample result and a detailed results are available in 47), along with their corresponding failure modes. Table 2 summarises the test results for U1 and R1-R7, identified as PT-U1 through PT-R7, where PT denotes the test load. For clarity and ease of comparison with design predictions, the load-displacement plots are expressed in terms of the  $PT/P_n$  ratio, where PT represents the experimental load obtained from the tests and  $P_n$  denotes the factored design load determined using the Direct Strength Method of AISI.

The load-displacement relationships demonstrate an initial phase of constant axial stiffness up to the onset of local buckling (at load  $P_{cr}$ ). Beyond this point, stiffness gradually decreases as lateral displacement develops. All CFS specimens exhibited post-buckling reserve strength, with thinner channels ( $t_b = 0.475$  mm) showing notably higher reserve strength ( $P_T/P_{cr} > 7$ ), whereas thicker specimens displayed lower post-buckling reserves ( $P_T/P_{cr} \leq 1.9$ ). Although these load–displacement responses are relatively straightforward, they must be carefully analysed in the context of repeated loading to inform practical design guidelines for the reuse of previously employed members, akin to a structural material passport [3, 21, 63-65].

According to ISO 20887, components intended for direct reuse should retain their original material, structural, and functional properties. However, these general criteria do not universally apply across all materials, load conditions, and structural configurations. In practice, it is impossible to fully preserve the original structural characteristics of reused components. Nevertheless, these members can be effectively redesigned based on their residual material and structural capacity, accounting for the associated degree of uncertainty.

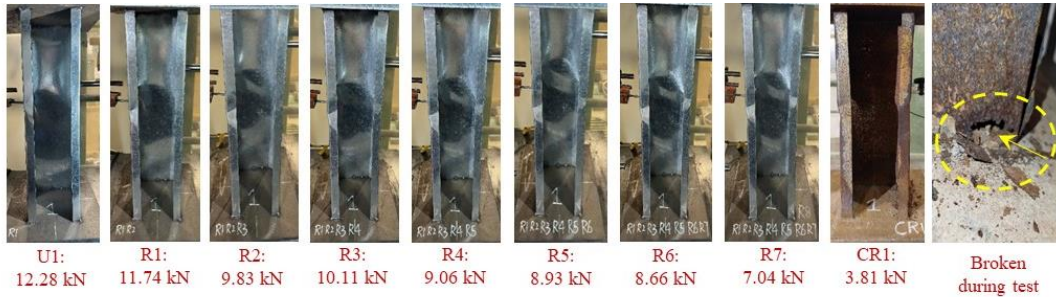
To evaluate the residual strength of CFS members-particularly those prone to buckling within the elastic range-this study introduces specific design criteria and assumptions to facilitate comparison between original (U1, first-use) and reused (R1–R7) members:

- The axial stiffness and compressive strength of the reused member should remain comparable to those of the original, or the axial stiffness alone should be within approximately 90% of that of the original member.
- The geometric configuration, including shape and dimensions, should either remain unchanged or within acceptable tolerance limits to prevent instability failure near the target design load.
- The material properties of the reused member-specifically Young’s modulus, yield strength, ultimate strength, and elongation-should remain consistent after reuse.

The structural behavior of cold-formed steel (CFS) columns subjected to reuse tests can be categorized into two key aspects: (i) degradation in stiffness and strength, and (ii) feasibility of reuse in structural applications, as outlined below.

**Stiffness Comparison:** Degradation in column stiffness reduces load-carrying capacity and affects overall structural stability, necessitating careful consideration in reuse design. All tested CFS columns were locally slender ( $\lambda_1 = 2.16-6.27$ ). Highly slender columns ( $\lambda_1 = 6.27$ ) exhibited a substantial stiffness reduction soon after reaching the design load ( $P_n$ ) during the initial test (U1), whereas those with  $\lambda_1 < 3.21$  maintained stiffness until loading reached  $P_n$ . This difference

corresponds directly to local slenderness variations. Results from reuse tests (R1-R7) show a progressive stiffness loss due to accumulated local deformations from previous loadings. The maximum stiffness reduction reached 34-42% at R7 compared with U1, averaging 5.22% per reuse. Despite two-day intervals between tests simulating deconstruction and reuse, residual deformation persisted. As stiffness loss compromises structural stability, reuse of members with significant stiffness degradation is not recommended. Test data suggest that up to two reuses (R2) are feasible, with stiffness loss below 10%.



(a) Repeated Reuse tests R1-R8 : Plain columns  $t_b = 0.475$  mm

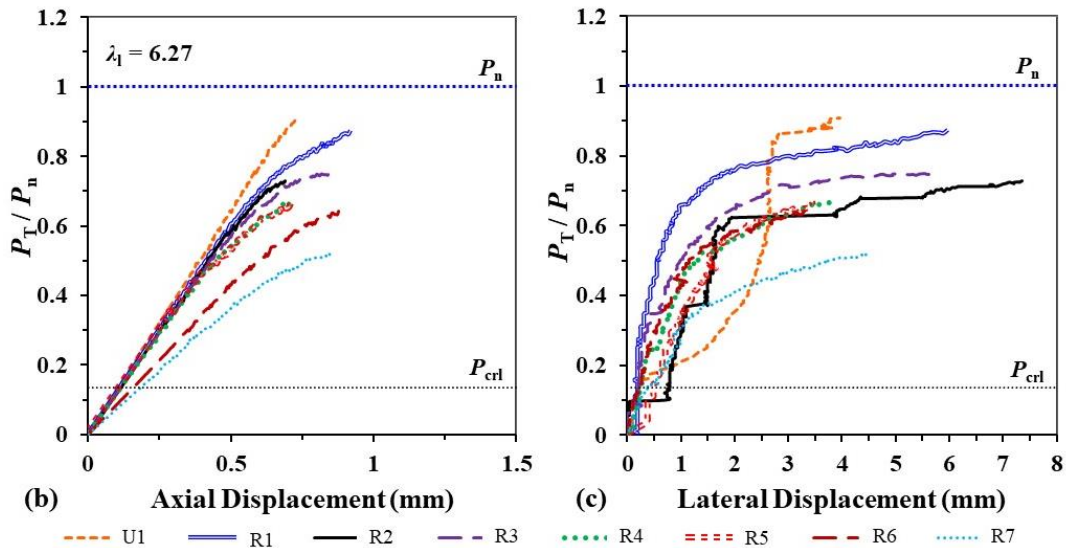


Figure 3: 0.5-P-1 Repeated reuse tests: (a) Failure mode; (b-c) Structural response.

**Axial Strength Comparison:** Each loading (U1, R1-R7) was applied up to  $P_n$ , with unloading initiated at stiffness degradation points to prevent large deformations. The degradation point decreased progressively with reuse ( $PT-R1 > PT-R2 > \dots > PT-R7$ ; Table 2), indicating declining strength despite loading within the elastic limit ( $P_n < P_y$ ). This reduction results from deformation accumulation and high local slenderness, possibly compounded by material property variations through repeated loading. High-slenderness specimens ( $t_b=0.475$  mm,  $\lambda_1=6.27$ ) exhibited the largest strength reduction ( $PT = 0.52P_n$ ), while 0.97 mm ( $\lambda_1=3.21$ ) and 1.47 mm ( $\lambda_1=2.16$ ) columns showed moderate and minimal reductions ( $PT = 0.67P_n$  and  $0.97P_n$ , respectively). The latter's limited strength deterioration ( $<5\%$  even at R7) resulted from lower imperfections and slenderness. To ensure safety, both stiffness and strength degradation should be incorporated via a reuse resistance factor ( $\phi_R$ ) to quantify reusable strength ( $P_{n-R}$ ).

**Influence of Embossment on Failure Modes:** Embossment exhibited minimal influence on the axial capacity or stiffness of 0.475 mm-thick channels due to their high slenderness. Slight improvements in lateral stiffness were observed for thicker (0.97 and 1.47 mm) sections, attributable to minor stiffening from embossments. Failure images (Fig. 3a) showed reduced local buckling deformation with increasing embossment depth (Plain > Small > Medium > Large), yet overall strength enhancement from embossment remained negligible. Consequently, embossed geometry can be excluded from finite strip analyses and the plain-section buckling strength ( $P_{cr}$ ) adopted for design.

**Overall Conclusion:** Based on 192 reuse tests (Task 1), CFS columns subjected to local buckling can be reused under controlled conditions, with limits on both the number of reuses and applied load levels. Further studies (Tasks 2–4) are required to establish design rules addressing (i) load limits via  $\phi_R$ , (ii) long-term corrosion effects, and (iii) changes in material properties after reuse.

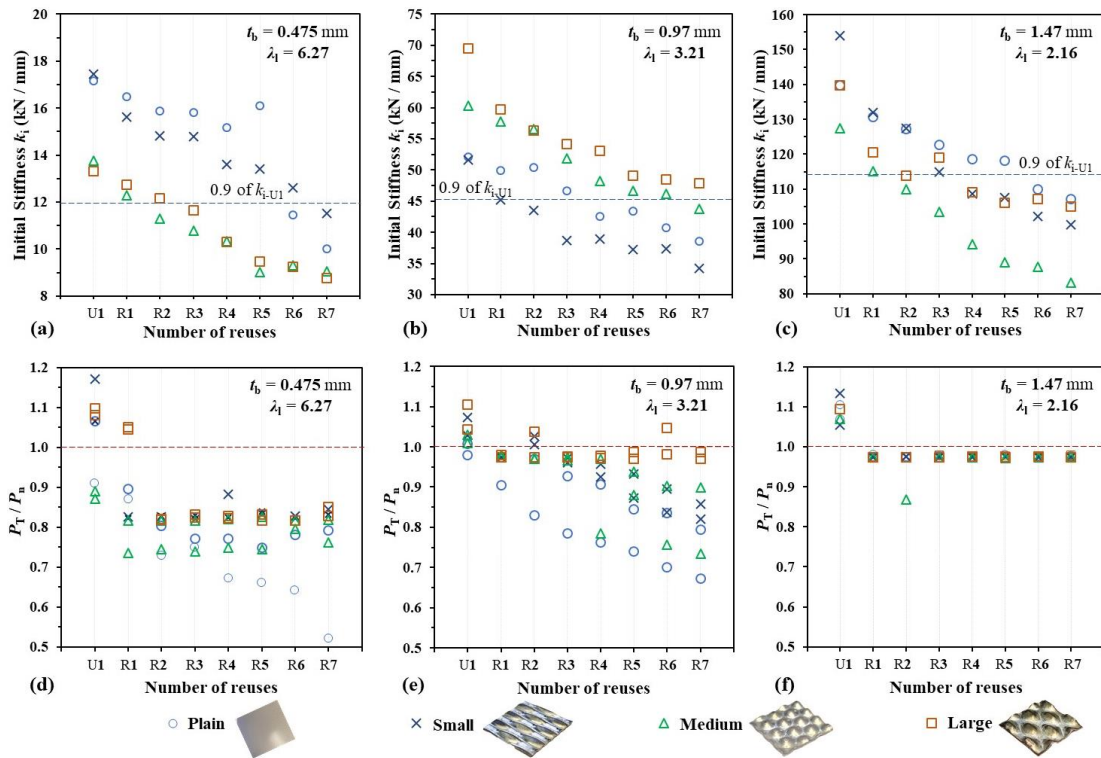


Figure 4: Evaluation of repeated test results ( $P_{T,U1} - P_{T,R7}$ ): (a-c) Variation of initial stiffness  $k_i$  of U1 with respect to number of reuses ( $0.9$  of  $k_{i,U1}$  is calculated from the minimum stiffness among all initial stiffnesses for the corresponding thickness); (d-f) Change in column strength with respect to number of reuses. U1 is the first use, and R1-R7 are the reuse tests.

Table 2: Task 1 Results: Repeated Reuse Tests for CFS Channel Section Members

Specimen ID	$\lambda_1$	$P_n$ (kN)	Reuse test results (kN) - for each cycle, it is attempted to load up to the factored design load ( $P_n$ ) or up to the loss of initial stiffness ( $k_i$ )								
			$P_{T,U1}$	$P_{T,R1}$	$P_{T,R2}$	$P_{T,R3}$	$P_{T,R4}$	$P_{T,R5}$	$P_{T,R6}$	$P_{T,R7}$	
0.5-P-1	6.27	13.49	12.28	11.74	9.83	10.11	9.06	8.93	8.66	7.04	

0.5-P-2	6.27	13.49	14.38	12.09	10.85	10.41	10.40	10.11	10.54	10.67
0.5-S-1	6.27	13.49	15.81	11.15	11.13	11.05	11.89	11.24	11.16	11.40
0.5-S-2	6.27	13.49	14.38	11.10	11.18	11.18	11.12	11.33	11.10	11.21
0.5-M-1	6.27	13.49	11.74	9.93	10.05	9.97	10.11	10.06	10.74	10.27
0.5-M-2	6.27	13.49	12.01	11.00	11.03	11.01	11.06	11.15	11.02	11.04
0.5-L-1	6.27	13.49	14.57	14.10	11.06	11.12	11.08	11.21	11.01	11.15
0.5-L-2	6.27	13.49	14.79	14.16	11.03	11.21	11.18	11.02	11.01	11.46
1.0-P-1	3.21	49.47	48.41	44.73	41.01	38.84	37.75	36.56	34.66	33.27
1.0-P-2	3.21	49.47	49.87	48.17	48.02	45.82	44.87	41.79	41.34	39.29
1.0-S-1	3.21	49.47	53.08	48.21	50.73	48.05	47.35	46.10	44.28	42.46
1.0-S-2	3.21	49.47	50.82	48.18	49.74	47.48	45.73	43.14	41.44	40.57
1.0-M-1	3.21	49.47	49.91	48.45	48.03	48.17	48.02	46.43	44.65	44.44
1.0-M-2	3.21	49.47	50.98	48.22	48.04	47.77	38.79	43.51	37.47	36.30
1.0-L-1	3.21	49.47	54.66	48.43	48.18	48.28	48.38	48.78	51.75	48.81
1.0-L-2	3.21	49.47	51.61	48.15	51.32	48.16	48.08	48.02	48.52	48.02
1.5-P-1	2.16	102.99	110.08	100.19	100.19	100.73	100.2	100.9	100.4	100.73
1.5-P-2	2.16	102.99	108.56	100.34	100.41	100.35	100.2	100.4	100.3	100.33
1.5-S-1	2.16	102.99	113.86	101.16	100.49	100.52	100.4	100.1	100.5	100.67
1.5-S-2	2.16	102.99	116.72	100.52	100.43	100.85	100.7	100.4	100.7	100.44
1.5-M-1	2.16	102.99	110.12	100.22	89.51	100.36	100.2	100.0	100.4	100.55
1.5-M-2	2.16	102.99	99.23	92.48	86.07	81.51	77.33	72.99	71.03	69.64
1.5-L-1	2.16	102.99	112.79	100.30	100.35	100.73	100.3	100.5	100.2	100.84
1.5-L-2	2.16	102.99	112.64	100.30	100.45	100.48	100.4	100.3	100.6	100.35

Notes: Please see Umaraj et al. [47] for the details of the units, symbols used.

This section corresponds to Task 2, which involves the determination of the reuse resistance factor ( $\phi_R$ ) and the effective number of reuses through a detailed assessment and analysis of the experimental results. The repeated reuse test results clearly indicate that the load capacity (stiffness degradation point) gradually decreases with an increasing number of reuses (U1-R7) (Fig. 4d-f, and Table 2). However, this degradation cannot be uniformly applied to all reuse cases, as a pronounced drop in stiffness occurs after the second reuse (R2, Figs. 4a-c). Therefore, both stiffness and strength must be considered in the design for reuse. Furthermore, a significant reduction in load capacity is observed in the thinnest cold-formed steel (CFS) specimens ( $t_b = 0.475$  mm), with  $PT-R7 = 0.52 P_n$  (Fig. 4d and Table 2). Consequently, reusing the 0.475 mm thick channel sections is inefficient, and no reuse resistance factor ( $\phi_R$ ) is considered for this thickness. A systematic procedure used to derive the reuse resistance factor ( $\phi_R$ ) for predicting the reusable strength ( $P_{n-R}$ ) is outlined below.

**Step 1:** Determine the change in load-carrying capacity after each reuse test (R1-R7) relative to the initial test (U1). For example, the ratio between U1 and R1 defines  $\phi_{R1} = (R_1 / U1)$ . Similarly, ratios for subsequent reuse tests with respect to U1 are determined ( $\phi_{Ri} = R_i / U1$ ), where U1 represents the factored design load  $P_n$  (from Table 2). The  $\phi_{Ri}$  values are obtained for the 0.97 mm and 1.47 mm thick channel columns, excluding the 0.475 mm thick channels due to their poor reuse performance (see Fig. 4d).

**Step 2:** Compute the average values of  $\phi_{Ri}$  for each reuse instance (R1-R7) for the 0.97 mm and 1.47 mm thick channel columns, as summarized in Fig. 5. The  $\phi_{Ri}$  values for these two thicknesses

are nearly identical between R1 and R3 but diverge significantly from R4 to R7, attributed to differences in slenderness ratios and local imperfection magnitudes.

**Step 3:** Select the minimum  $\phi_{Ri}$  values for the 0.97 mm and 1.47 mm thick channel columns to establish the reuse resistance factor ( $\phi_R$ ) for safe reuse load determination ( $P_{n-R}$ ), as shown in Fig. 5.

$$\phi_{Ri} = 0.83 - 0.018 R_i \quad (\text{Eqn. 1})$$

The resulting linear regression relationship for  $\phi_{Ri}$  provides a statistically accurate (coefficient of determination = 0.99) yet conservative expression for reuse design. Although reliable, this expression is recommended only up to the second reuse ( $i = 2$  for  $R_i$  in Eq. 1) due to substantial stiffness degradation beyond R2 (Figs. 4b-c). Based on Eq. 1, the values of  $\phi_R$  for the first (R1) and second (R2) reuse are 0.81 and 0.79, respectively. This minor variation aligns with established CFS design practices, where small changes in resistance factors ( $\phi_c$ ) are preferred for accurate strength predictions [66-68].

The derived reuse resistance factors ( $\phi_R$ ) were validated by comparing the predicted reusable strength ( $P_{n-R}$ ) with the corresponding experimental results ( $P_T$ ) presented in [47]. The comparison confirms that the  $\phi_R$  values from Eq. 1 provide accurate predictions, with mean ratios of  $P_{T-R}/P_{n-R}$  equal to 1.19 and 1.20 for the first and second reuse, respectively. Moreover, reliability analysis following AISI demonstrates that the results are structurally safe ( $\beta > \beta_{\text{target}} = 2.5$  per Section K2 of AISI S100). According to this reuse design framework, CFS channels exhibiting local buckling can be safely reused up to 67.15-68.85% of their original design strength ( $P_n$ ) for the first and second reuse, indicating efficient structural performance.

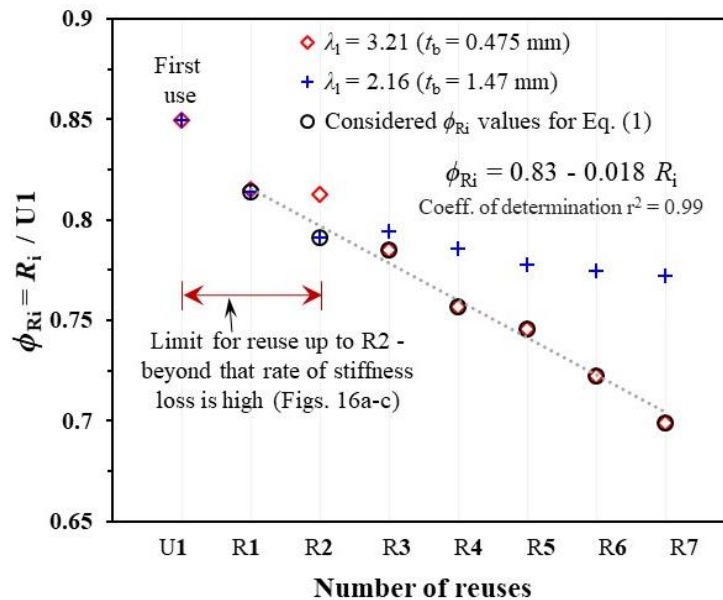


Figure 5: Proposed relationship for the Reuse Resistance Factor ( $\phi_{Ri}$ ) (minimum values of  $\phi_{Ri}$  are taken from 0.97 mm and 1.47 mm thick channel columns)

Table 3: Comparative assessment of predicted remaining strength ( $P_{nR}$  using  $\phi_R$ )

Specimen ID	$\lambda_1$	First use design strength $P_n$	First reuse design strength $P_{n-R1}$	Second reuse design strength $P_{n-R2}$	Comparison*	
		From DSM of AISI [50]	$P_{n-R1} = P_n \times \phi_{R1}$ $\phi_{R1} = 0.83 - 0.018(1) = 0.81$	$P_{n-R2} = P_n \times \phi_{R2}$ $\phi_{R2} = 0.83 - 0.018(2) = 0.79$	$P_{T-R1} / P_n$ R1	$P_{T-R2} / P_{n-R2}$
0.5-P-1	6.27	13.49	10.96	10.71	1.18	1.08
0.5-P-2					1.22	1.20
0.5-S-1					1.12	1.23
0.5-S-2					1.12	1.23
0.5-M-1					1.00	1.11
0.5-M-2					1.11	1.22
0.5-L-1					1.42	1.22
0.5-L-2					1.43	1.22
1.0-P-1	3.21	49.47	40.17	39.28	1.12	1.05
1.0-P-2					1.20	1.23
1.0-S-1					1.20	1.30
1.0-S-2					1.20	1.27
1.0-M-1					1.21	1.23
1.0-M-2					1.20	1.23
1.0-L-1					1.21	1.23
1.0-L-2					1.20	1.31
1.5-P-1	2.16	102.99	83.63	81.77	1.20	1.23
1.5-P-2					1.20	1.23
1.5-S-1					1.21	1.23
1.5-S-2					1.20	1.23
1.5-M-1					1.20	1.10
1.5-M-2					1.11	1.06
1.5-L-1					1.20	1.23
1.5-L-2					1.20	1.23
				Max	1.43	1.31
				Min	1.00	1.05
				Mean	1.19	1.20
				Std. Dev	0.088	0.071
				CoV	0.073	0.059
				Reliability index - $\beta$	2.79	2.85

Note: \*Maximum number of reuses limited to R2 (two reuses after first use) to avoid potential instability failure due to significant stiffness loss (Fig. 4b-c). Values of  $P_{T-R1}$  and  $P_{T-R2}$  are from Table 2.

Task 3 (assessing the corrosion and material effects in reuse) and Task 4 (influence of material characteristics) are explained in detail in Umaraj et al (2025) [47].

#### 4. Practical Significance of Reuse Design for CFS Members

From the structural reuse performance of cold-formed steel (CFS) channel sections observed in Tasks 1-4 (192 reuse tests for U1-R7 in Figs. 4-5 and 39 corrosion tests for  $P_{CR1}$ - $P_{CRU}$  - See [47]), the following aspects of practical significance regarding CFS reuse are highlighted:

CFS channel columns with thicknesses less than or equal to 0.5 mm, which predominantly experience pure local buckling, are unsuitable for reuse due to the high risk of fracture after prolonged corrosion exposure. However, the authors’ recent work demonstrated that thin CFS angle columns (0.5 mm thick) can be reused when the primary failure mode is local–global interaction buckling. Together, these findings suggest that the reuse potential of thin CFS sections is governed by the buckling mode. Nevertheless, from a safety perspective, the reuse of thin CFS sections ( $\leq 0.5$  mm) is not recommended.

CFS channel columns with thicknesses between 0.97 mm and 1.47 mm can be reused at least twice while maintaining adequate performance, as all specimens satisfied the factored design load capacity ( $P_{n-R2}$  with  $\phi_R$ ), even after accounting for long-term corrosion effects. It is worth noting that these specimens exhibited high slenderness ratios ( $\lambda_1 = 2.16-3.21$ ), substantially exceeding the conventional industrial limit ( $\lambda_1 < 1.5$ ) [69-78]. Despite their slenderness, the residual load-bearing capacity after repeated reuse and corrosion remained satisfactory (see reference 47). Therefore, CFS columns within a local slenderness range of 2.16-3.21 can be considered for inclusion in reuse-oriented design frameworks, such as SCI and PROGRESS, under both “design rules for new structural components intended for future reuse” and “design rules for used components designated for direct reuse.”

The original material properties of the CFS sections can be used to predict their reusable strength up to the second reuse stage. However, for improved accuracy and safety, it is recommended that the reduced yield and tensile strengths defined in Section A3.1.2 of AISI S100 (2024) be adopted. Reclaimed CFS structural members intended for direct reuse must comply with the dimensional and straightness tolerances specified in Table A5-3 of AISI S240 (2020). Meeting these tolerances is essential for accurately predicting residual strength.

Finally, it should be emphasized that the proposed reuse design recommendations are derived from experimental tests covering a local slenderness range of 2.16-3.21. Because CFS sections often experience complex buckling phenomena, each instability mode requires separate consideration during design [79-85]. In particular, CFS members governed by pure global buckling may not be reusable due to the sudden loss of load-carrying capacity after global instability, which lacks post-buckling strength. Nonetheless, reuse may remain feasible for such members if intermediate bracing is introduced. As summarized in Table 4, further research is necessary to refine resistance factors and expand reuse design provisions for cold-formed steel structural members. Additional investigations should also explore other relevant factors influencing reuse in CFS structures.

Table 4: First use ( $\phi_c$ ) and reuse ( $\phi_R$ ) resistance factors for buckling modes of CFS columns

CFS member buckling modes	First use Resistance factor ( $\phi_c$ ) [50]*	Reuse resistance factor ( $\phi_R$ )	
	U1	R1	R2
Local buckling (present study)	0.85	0.81	0.79
Local-global interaction mode [65]	0.85	0.72	0.72
Other buckling modes	0.85	To be determined in future research	

Note:  $\phi_R$  - additional resistance factor not replacing the conventional  $\phi_c$ ; \* $\phi_c$  - first reuse resistance factor obtained from AISI S100 [50]. These suggested reuse resistance factors are applicable for

both “design for direct reuse of components” - preparing and designing new structural members for future repeated reuses, and “design of used components for direct use” - preparing already used components for reuse.

## Conclusions

This study experimentally investigates the reuse potential of cold-formed steel (CFS) short columns. Reuse concepts, design approaches, and feasibility were evaluated through 231 repeated loading tests, considering long-term corrosion and material variability.

Results show that CFS members with local normalized slenderness ( $\lambda_1 < 3.21$ ) can be safely reused twice beyond their initial service life, while sections thinner than 0.5 mm are unsuitable due to corrosion vulnerability. A reuse resistance factor ( $\phi_R$ ) was introduced to determine the reusable design strength ( $P_{n-R} = \phi_c \times \phi_R \times P_n$ ), with original material properties applicable for strength prediction and AISI reductions providing a conservative estimate. The proposed rules, validated under accelerated corrosion, are reliable for the tested geometries but require further verification for other configurations, failure modes, and loading conditions. A more detailed, comprehensive and extensive version of this research work is published in Umaraj et al. (2025) [47].

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