A Detailed History of Distortional Buckling of Columns

A History of Distortional Buckling of Cold-Formed Steel Columns

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Research in the behavior of cold-formed steel columns spans approximately fifty years. Through that time distortional buckling, under many different names, has come in and out of the spotlight. This brief account highlights the major experimental work in cold-formed steel column research. Theoretical trends are also briefly mentioned, particularly as they relate to distortional buckling. Though distortional buckling in beams and columns is intimately tied together an attempt is made to focus only on the column research.

<table>
<thead>
<tr>
<th>Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
</tr>
<tr>
<td>1940's and 1950's</td>
</tr>
<tr>
<td>1960's</td>
</tr>
<tr>
<td>1970's</td>
</tr>
<tr>
<td>1980's</td>
</tr>
<tr>
<td>1990 to Present</td>
</tr>
</tbody>
</table>
The 1940’s and 1950’s
Cold-formed steel column research began in the 1940’s with proprietary testing at Cornell University (Winter 1940, Winter 1943). Winter (1949) summarized the state of the art for the 1940’s. Chilver (1951, 1953) and Harvey (1953) summarized the experimental and theoretical thin-walled column research in Britain. After fifty years of progress, modern column research is still similar to Chilver’s work: elastic stability solutions for local plate buckling and “effective width” for the ultimate strength.

The elastic plate buckling solution was based on Lundquist and Stowell (1943) who extended the work of Timoshenko and Gere (1936) by providing practical methods for calculating the stability of connected plates. The “effective width” solution was based on von Kármán et al. (1932) and the experimental corrections of Winter (1947). Notably, both Chilver and Harvey properly included the interaction of elements in determining the local buckling stress. Also, for lipped channels Chilver stated that the reinforcing “lip” should be sufficiently stiff to insure local buckling (and thus avoid distortional buckling), but gave no criteria for achieving this.

The 1960’s
At Cornell, cold-formed steel column research in the 1960’s primarily ignored distortional buckling as work focused on material properties (Karren 1965, Karren and Winter 1967, Uribe and Winter 1969), and the behavior of long columns (Chajes et al. 1966, Peköz 1969). Karren showed significant variation in engineering properties around the cross-section; notable, since this fact is widely ignored in current research on distortional buckling. The experimental method used by Karren – compression testing of back to back connected specimens – would also later be used by Cornell researchers. At the same time researchers in Canada examined optimizing the geometry of cold-formed columns and edge stiffeners (Divakaran 1964, Venkataramaiah 1971).

Aluminum researchers in the 1960’s investigated lipped channels and hats experimentally (Dwight 1963) and analytically (Sharp 1966). Sharp presented an early theoretical treatment of distortional buckling, or as he termed it “overall” buckling. Under simplifications about the rotational restraint at the web/flange juncture the distortional buckling stress of a lipped channel was approximated. Dwight’s experiments were used for verification.

A folded plate method was developed at Purdue University (Goldberg, Bogdanoff and Glauz 1964) to predict the lateral and torsional buckling of thin-walled beams including sectional distortion. The method demonstrated distortional buckling of open sections under both compressive axial and bending load. At about the same time, an exact stiffness method was developed in the UK by Wittrick (1968a, 1968b) for studying the buckling of stiffened panels in compression. Although only stiffened panels, and not open section members, were investigated, distortional buckling modes (called torsional modes) were discovered.

The 1970’s
Across the world, column research in the 1970’s focused on the interaction between local and overall (i.e, global – flexural, torsional, flexural-torsional) buckling modes (DeWolff 1974, Klöppel and Bilstien 1976, Rhodes and Harvey 1977, Peköz 1977, Loughlan 1979). At Cornell, work also continued on unstiffened elements (Kalyanaraman et al. 1977) and on intermediate and edge stiffeners (Desmond 1977). In Germany isolated edge stiffeners were studied experimentally and analytically by physically replacing the web/flange juncture with a simple support, thus providing known boundary conditions (Kloppel and Unger 1970).
Desmond’s (1977) work forms the basis for the modern AISI (1996) Specification on edge stiffened elements. In that work, the term “stiffener” buckling describes the distortional mode. For design purposes, Chilver stated that a “lip” should have sufficient stiffness to insure that local buckling occurs. Desmond recognized that elastic buckling criteria (i.e., ensuring that “stiffener” buckling is a higher critical stress than local buckling) does not meet Chilver’s criteria. Using experimental data Desmond empirically formulated rules for an adequate “lip” stiffener. An adequate stiffener is not always economical and thus Desmond provided a single empirical solution for the buckling coefficient, \( k \), of an edge stiffened element in either local or “stiffener” buckling. As a result, distortional buckling was incorporated into the AISI Specification as another local mode and was not treated as explicitly different from local plate buckling. Desmond’s (and Kalyanaraman’s) experimental studies, followed Karren, and thus the specimens were formed by connecting two members back to back. In the resulting specimen, the web thickness is twice that of the flange. The distortional buckling stress is artificially elevated due to higher than normal rotational stiffness at the web/flange juncture provided by the web.

In Sweden, Thomasson (1978) performed experiments on lipped channels with slender webs. In order to elevate the local buckling stress of the webs small groove stiffeners were folded in. This eliminated the local buckling problem, but created what Thomasson called a “local-torsional” problem – i.e., distortional buckling. This is a recurring theme for distortional buckling – optimization to remove a local mode creates a distortional problem. Thomasson considered this “local-torsional” mode undesirable and thus put closely spaced braces from lip to lip, insuring that distortional buckling did not occur and therefore making the local mode again dominant.

The 1980’s
At Cornell research focused on imperfections and residual stresses (Dat 1980, Weng 1987), local buckling interaction (Mulligan 1983), beam-columns (Loh 1985), and the formalization of a unified effective width approach (Peköz 1987). Mulligan (1983) encountered distortional buckling in testing, and followed Thomasson’s terminology thus calling the mode “local-torsional”. Mulligan observed that Desmond’s adequate moment of inertia criteria did not appear to restrain this local-torsional mode in many cases. However, in the end, Mulligan chose to provide braces in a manner similar to Thomasson and distortional buckling was restricted in order to study local buckling phenomena.

In Europe, researchers such as Batista et al. (1987) continued to provide strong evidence for interaction of local and overall column buckling. At the University of Strathclyde research on local and overall interaction continued (Rhodes and Loughlan 1980, Zaras and Rhodes 1987) as well as studies on the behavior of isolated lip stiffened elements (Lim 1985, Lim and Rhodes 1986). Lim (1985) took the same experimental approach as Klöppel and Unger (1970). The “torsional” mode (distortional buckling) for these flanges may be accurately predicted due to the special boundary conditions.

In the 1980’s some researchers began to focus on distortional buckling. This trend was most evident at the University of Sydney. The need to investigate the behavior of cold-formed steel storage racks lead to work on distortional buckling (Hancock 1985, Lau 1988). The optimized nature of storage rack columns insured that distortional buckling often dominated. Hancock extended and popularized Cheung’s (1976) finite strip analysis as a tool for understanding the buckling modes in thin-walled members. The specific version of the finite strip method which
could account for both plate flexural buckling and membrane buckling in thin-walled members was developed by Plank and Wittrick (1974). Lau extended the finite strip buckling capabilities to the spline finite strip method (Cheung and Fan, 1983) to allow for fixed-ended boundary conditions, performed experiments in which distortional buckling was the failure mechanism (Lau and Hancock, 1990), and generated a hand method (Lau and Hancock, 1987) for predicting the elastic distortional buckling stress. The hand method used classical analytical techniques similar to Sharp (1966) but included web instability in the model which had not been considered by Sharp.

In Japan, several authors (Hikosaka, Takami and Maruyama, 1987, Takahashi 1988) published papers on the prediction of distortional buckling of thin-walled members with polygonal cross-section.

In the USA, Sridharan (1982) developed the finite strip method to study post-buckling in the distortional mode (called local-torsional) and demonstrated the rapid increase in membrane stress at the tips of edge-stiffening lips after distortional buckling. This indicated that the post-buckling reserve in the distortional mode may not be as great as the local mode since yielding would occur earlier in the post-buckling range.

1990 to Present
In Europe, column testing continued, Moldovan (1994). Eurocode 3 Part 1.3 (1996) provided a method for predicting the distortional buckling of simple lipped sections such as channels accounting for the restraint provided by the web and the flange to the lip buckling as a strut. This method accounted for the distortional deformations of the web and flange but used a column curve for the failure of the lip so that there was no post-buckling reserve in the distortional mode. Testing of HSS Channels was performed at the Technical Research Centre of Finland (Salmi and Talja, 1993) and the sections underwent distortional buckling in some cases. The results were compared with the Eurocode method including modifications to improve it.

At the University of Missouri-Rolla work on the effect of strain rate on columns was conducted (Kasser et al. 1992). At Cornell, further research on load eccentricity effects and web perforations were conducted (Miller and Peköz 1994). Research in Canada and at Texas-Austin examined Z section columns and provided further experimental evidence of distortional failures and problems in the AISI Specification (Polyzois and Sudharampal 1990, Purnadi et al. 1990, Polyzois and Charvarichborikarn 1993).

University of Sydney research on distortional buckling continued in the 1990’s (Kwon 1992, Kwon and Hancock 1992, Hancock et al. 1994). Kwon conducted experiments on lipped channels with and without groove stiffeners in the web. The distortional mode was unrestricted and the tests showed that interaction of distortional buckling with other modes is weak. Distortional buckling was experimentally observed to have lower post-buckling capacity than local buckling. The results were summarized and new column strength curves suggested for distortional failures in Hancock et al. (1994). Research also continued on local and overall column buckling interaction. Rasmussen and Hancock (1991) showed the importance of different end fixity on the post-buckling behavior. Young (1997) experimentally demonstrated that fixed ended columns do not suffer the same interaction problems as pin ended columns. Young also observed that the interaction of distortional buckling with other modes is weak.
The University of Strathclyde conducted studies directly related to “torsional” buckling, i.e., distortional buckling (Seah 1989, Seah et al. 1991, Seah and Rhodes 1993). Seah investigated hats and channels with compound lips. Seah developed hand methods for the prediction of distortional buckling similar to Lau’s and Sharp’s treatments. For ultimate strength Seah and Rhodes’s treated the distortional mode in a manner similar to local buckling. Thus, they proposed an effective width approach rather than the column curve approach proposed by Sydney researchers. In addition, Chou, Seah and Rhodes (1996) summarized the state of the art prediction abilities of cold-formed steel design specifications. Limitations and discrepancies were found in all major design specifications.

In the 1990’s Generalized Beam Theory (GBT) (theory: Schardt 1989, Davies et al. 1994) has become a useful tool to study distortional buckling of columns (applications: Schardt 1994, Davies and Jiang 1996). Using GBT, Davies and Jiang argued that distortional buckling has weak interactions with other modes. GBT is currently only applicable in elastic problems, but Davies and Jiang endorsed the column strength curves of Hancock et al. (1994) for ultimate strength prediction.

Using finite strip and finite element analysis Schafer (1997) demonstrated that the distortional mode has greater imperfection sensitivity than local modes. Schafer also observed that distortional failures have lower post-buckling strength than local failures. New hand methods for predicting distortional buckling that are a hybrid of the finite strip method and the classic hand methods used by Sharp (1966) are presented and verified. Schafer (1998) explicitly showed that the AISI Specification equations (via Desmond) over-predict the distortional buckling stress, particularly as the ratio of the web height to flange width becomes large.

The Australian Standard for Steel Storage Racking (1993) and the Australian/New Zealand Standard for Cold-Formed Steel Structures (1996) were developed to contain explicit design rules for distortional buckling in compression.


Kwon, Y.B., and Hancock, G.J., “Strength Tests of Cold-Formed Channel Sections undergoing Local and Distortional Buckling”. Jour Struct Engg, ASCE, 117(2), pp 1786 – 1803.


Standards Australia/Standards New Zealand (1996), “Cold-Formed Steel Structures”, AS/NZS 4600.


B Example: Hand Calculation of Local and Distortional Buckling
C Detailed Elastic Buckling Results
D Example: Design Examples for Considered Methods
E Detailed Ultimate Strength Results
F Recommended Specification Changes
   F.1 New commentary language recommended for immediate adoption
   F.2 New Effective Width Procedures recommended for interim adoption
   F.3 Direct Strength method recommended for interim adoption as an alternative procedure and long-term adoption as design method