



## Ductility of Reinforcement - Research History

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There is a growing focus on the ductility of reinforcing steels following the introduction of low and normal ductility classes of steel in the Australian Standard, AS4671-2001, Steel Reinforcing Materials. The minimum ductility requirements of the two classes were based on the European Pre-Standard DDENV 10080.

The Concrete Structures code, AS3600-2001, provides design rules for the use of both Class L And Class N reinforcing steels. Hot rolled reinforcing bars are Class N while cold reduced wire in mesh is Class L steel. There has been some debate about the use of Class L mesh in suspended slabs. AS3600–2001 does allow the use of Class L reinforcement in structural elements and there are appropriate design rules to ensure that safe designs are achieved.

European research has been going on for over sixty years as will be seen from the information presented below. In Australia, research and testing into the performance of 500 grade reinforcing steels commenced in the mid 1990's. Some of the important research papers on ductility are listed below.

### Early work:

1935-8	Glanville et al - London
1945+	Baker et al - London
1960-7	Baker, Amarakone et al - Comite Europeen de Beton 18 laboratories in 13 countries, examining the rules governing the ductility of concrete beams.
1972	BS Code of Practice 110

### More recent detailed work:

1987	Langer & Eligehausen - Stuttgart "The 1967 CEB work could be unsafe in many situations." "1960's reinforcement more ductile than 1980's steels."
1990	CEB Model Code differentiated between hot rolled and cold rolled steels

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| 1992   | Eurocode EC2<br>set minimum Uniform Elongations (Agt) for two levels of ductility in reinforcing steels. |
| 1994-5 | Beeby Leeds UK<br>research into performance of different steels to validate the ductility levels.        |
| 2006   | Patrick M.<br>Paper on the safe design using Class L reinforcement.                                      |

Further information:

Numerous papers and publications have been written on the subject, the more significant ones being :-

1. Macchi, G. Ductility Condition for Simplified Design Without Check of Compatibility. CEB Bulletin d' Information No. 105, Paris, 1976.
2. Langer, P. Verdrehfähigkeit Plastizierter Tragwerksbereiche im Stahlbetonbau. Institut für Werkstoffe im Bauwesen, Universität Stuttgart, Report 1987/1.
3. Eligehausen, R and Langer, P. Rotation Capacity of plastic hinges and moment redistribution. Bulletin d' Information No. 175. Comite Euro-International du Beton, Lausanne, 1987.
4. Comite Euro-International du Beton. Ductility - Reinforcement. Bulletin d' Information No 218. Progress Report of Task Force Group 2.2, "Ductility Requirements for Structural Concrete - Reinforcement". CEB, Lausanne, 1993. (Contains numerous papers and references on the subject of reinforcement ductility - Preface by Eligehausen).
5. CEB-FIP Model Code 1978, Lausanne.
6. CEB-FIP Model Code 1990. CEB Bulletin d' Information No 195, Lausanne.
7. CEB-FIP Model Code 1990. No 213/214 CEB, Lausanne.
8. Eurocode 2: Design of Concrete Structures, Part 1. General Rules and Rules for Buildings, DD ENV 1992-1-1: 1992.
9. Litzner, H-U. Wiesbaden. European Standardization - Possible Effects on the Reinforcement. 1995
10. Beeby, AW. Ductility of Reinforced Concrete Members. The Concrete Society. London 1996
11. Russwurm, D. Beton- und Stahlbetonbau. Duktilität (Ductility), Berlin 1992
12. Russwurm, D. Beton- und Stahlbetonbau. New Findings Concerning the Question of the Ductility of Reinforcing Steel. 1995

13. Eurocode 4: Design of Composite Steel and Concrete Structures, Part 1..1 General Rules and Rules for Buildings, DD ENV 1994-1-1: 1994
14. British Standards Institute. BS 5950, Composite Steel and Concrete Structures.
15. Patrick, M, Akbarshahi, E and Warner, R. Ductility Limits for the design of Concrete Structures containing High Strength, Low Elongation Reinforcement. Concrete Institute of Australia. Concrete 97, Adelaide.
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Patrick, E. Akbarshahi, R.F. Warner.  
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18. Australian 500 MPa Reinforcing Steels and New AS 3600 Ductility Design Provisions.  
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19. Factors Affecting the Ductility of Stiffened Rafts.  
Adams, P. Walsh, W. Marsden, M. Patrick.  
Conference Proceedings, Concrete Institute of Australia, Concrete 99.  
Sydney, May 1999.
20. Ductility of Reinforced-Concrete Beams and Slabs and AS3600 Design Requirements.  
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21. Utilisation of Ductility of 500 MPa Steel Reinforcement in Reinforced Concrete Structures Designed to AS3600-2001.  
Patrick, M. Turner, R. Warner.  
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22. New Crack Control Design Provisions in AS3600-2001  
Wheeler, M. Patrick, R. Bridge.  
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23. Moment Re-distribution in Indeterminate RC Beams and Slabs with 500 MPa Grade, Class L and Class N Reinforcing Steels.  
Gravina, R. Warner  
Proceedings, Concrete Institute of Australia, Biennial Conference 2001, Perth
24. Design of Concrete Columns to AS3600-2001.

- Wheeler, R. Bridge  
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Proceedings, Concrete Institute of Australia, Biennial Conference,  
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26. Review of Effect of Reinforcing Bar Properties on Bending Performance.  
O'Grady, H. Goldsworthy, B. Smith.  
Proceedings, Concrete Institute of Australia, Biennial Conference,  
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27. Ductility of Reinforced Concrete Flexural Members with 500 MPa Grade Steel  
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28. Ductility of 500 MPa Class L Mesh and Possible Support Settlement Effects.  
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29. Behaviour of One-way Continuous Reinforced Concrete Slabs.  
Siddique U.  
Proc. 22<sup>nd</sup> Biennial Conf. Melbourne, Oct 2005.
30. Safe Design of Slabs and Beams incorporating Class L Mesh  
Dr Mark Patrick.  
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