



contents

Acknowledgements	xv
Preface	xvii
Disclaimer	xix

CHAPTER 1

The Automobile Body	1
1.1 Description of Automobile Body Configurations	3
1.2 Body Terminology	4
1.3 Body Mass Benchmarking	5
1.4 Organization of Book	6
1.5 Scope of Book	7
References	7

CHAPTER 2

System Engineering	9
2.1 Systems Engineering and Requirements	10
2.2 Categories of Structural Requirements	15
2.3 The Locate and Retain Function	16
2.3.1 Locate and Retain for Front Suspension Attachment Structure	18
References	29

CHAPTER 3

Automotive Body Structural Elements	31
3.1 Overview of Classical Beam Behavior	31
3.1.1 Static Equilibrium at a Beam Section	32
3.1.2 Stress over a Beam Section	33
3.1.3 Beam Deflection	33

3.2	Design of Automotive Beam Sections	<u>37</u>
3.2.1	Bending of Nonsymmetric Beams	<u>37</u>
3.2.2	Point Loading of Thin-Walled Sections	<u>41</u>
3.3	Torsion of Thin-Wall Members	<u>47</u>
3.3.1	Torsion of Thin-Walled Members with Closed Section	<u>47</u>
3.3.2	Torsion of Members with Open Section	<u>51</u>
3.3.3	Warping of Open Sections under Torsion	<u>53</u>
3.3.4	Effect of Spot Welds on Structural Performance	<u>56</u>
	Peel versus Shear Loading Condition	<u>56</u>
	Longitudinal Stiffness of a Shear-Loaded Weld Flange	<u>59</u>
3.4	Thin-Wall Beam Section Design in Automobiles	<u>64</u>
3.5	Buckling of Thin-Walled Members	<u>71</u>
3.5.1	Plate Buckling	<u>71</u>
3.5.2	Identifying Plate Boundary Conditions in Practice	<u>75</u>
3.5.3	Post-Buckling Behavior of Plates	<u>77</u>
3.5.4	Effective Width	<u>79</u>
3.5.5	Thin-Walled Section Failure Criteria	<u>82</u>
3.5.6	Techniques to Inhibit Buckling	<u>85</u>
3.5.7	Note on the Use of High-Strength Steel	<u>89</u>
3.5.8	Note on Bifurcation and Initial Imperfection	<u>89</u>
3.6	Automobile Body Panels: Plates and Membranes	<u>93</u>
3.6.1	Curved Panel with Normal Loading	<u>93</u>
3.6.2	Normal Stiffness of Panels	<u>94</u>
3.6.3	Oil-Canning Resistance	<u>95</u>
3.6.4	Dent Resistance	<u>95</u>
3.6.5	In-Plane Loading of Panels	<u>98</u>
	Membrane-Shaped Panels	<u>98</u>
	Membrane Analogy	<u>99</u>
3.7	Summary: Automotive Structural Elements	<u>101</u>
	References	<u>102</u>

CHAPTER 4

Design for Body Bending 105

4.1	Body-Bending Strength Requirement	<u>105</u>
4.2	Body-Bending Stiffness Requirement	<u>108</u>

4.3	Internal Loads during Global Bending: Load Path Analysis	<u>114</u>
4.3.1	Summary: Bending Strength	<u>121</u>
4.4	Analysis of Body-Bending Stiffness	<u>121</u>
4.4.1	Importance of Joint Flexibility	<u>124</u>
4.4.2	Strain Energy and Stiffness	<u>128</u>
4.4.3	Note on the Bending Stiffness Changes due to Side Doors	<u>131</u>
4.4.4	Summary: Bending Stiffness	<u>132</u>
4.5	Principles of Good Joint Design	<u>133</u>
4.5.1	Examples of Body Joint Design	<u>137</u>
	A-Pillar-to-Hinge-Pillar Joint	<u>137</u>
	Hinge-Pillar-to-Rocker Joint	<u>138</u>
	Rocker-to-Floor-Cross Member Joint	<u>139</u>
4.5.2	Joint Behavior at Abrupt Geometric Transitions	<u>140</u>
4.5.3	Summary of Joint Design	<u>143</u>
	References	<u>144</u>

CHAPTER 5

	Design for Body Torsion	<u>147</u>
5.1	Body Torsion Strength Requirement	<u>147</u>
5.2	Body Torsion Stiffness Requirement	<u>149</u>
5.2.1	Ensure Good Handling	<u>149</u>
5.2.2	Ensure Solid Structural Feel	<u>151</u>
5.3	Internal Loads during Global Torsion: Load Path Analysis	<u>154</u>
5.3.1	Shear-Resistant Members	<u>154</u>
5.3.2	Summary: Torsion Strength	<u>164</u>
5.4	Analysis of Body Torsional Stiffness	<u>164</u>
5.4.1	Shear Strain Energy of a Surface	<u>165</u>
5.4.2	Energy Balance for Torque-Loaded Box	<u>165</u>
5.4.3	Series Spring Analogy	<u>166</u>
5.4.4	Effective Shear Rigidity for Structural Elements	<u>168</u>
	Examples Using Effective Shear Rigidity	<u>169</u>
5.4.5	Torsional Stiffness of a Vehicle Cabin	<u>176</u>
5.4.6	Summary: Torsion Stiffness	<u>179</u>
5.5	Torsional Stiffness of Convertibles and Framed Vehicles	<u>179</u>

5.5.1	Torsional Stiffness of Convertibles	<u>179</u>
5.5.2	Torsional Stiffness of Body-on-Frame Vehicles	<u>182</u>
5.5.3	Torsional Stiffness of a Ladder Frame	<u>187</u>
5.5.4	Torsional Stiffness of Backbone Frame Vehicles	<u>190</u>
5.5.5	Torsional Resistance of Sandwich Plates	<u>191</u>
	References	<u>194</u>

CHAPTER 6

Design for Crashworthiness 197

6.1	Standardized Safety Test Conditions and Requirements	<u>197</u>
6.2	Front Rigid Barrier	<u>198</u>
6.2.1	Basic Kinematic Model of Front Impact	<u>201</u>
6.2.2	Structural Requirements for Front Barrier	<u>204</u>
6.2.3	Beam Sizing for Energy Absorption	<u>206</u>
6.2.4	Beam Sizing for Cabin Reaction Structure	<u>209</u>
6.2.5	Limit Analysis Design	<u>210</u>
6.2.6	Plastic Hinge Behavior	<u>211</u>
6.2.7	Design for Reducing Vehicle Pitch during Impact	<u>217</u>
6.2.8	Summary: Structure for Front Barrier Impact	<u>219</u>
6.3	Side Impact	<u>219</u>
6.3.1	Kinematic and Load Path Analysis of Side Impact	<u>222</u>
6.3.2	Flow Down of Requirements for Side Impact	<u>227</u>
	Crush Load for the Vehicle Side	<u>227</u>
	Clearance between the Occupant Shoulder and Door Panel	<u>228</u>
	Door Inner Crush Characteristic	<u>228</u>
6.4	Small Offset Rigid Barrier	<u>230</u>
6.4.1	Performance of Pre-Small Offset Rigid Barrier designs	<u>231</u>
6.4.2	Small Offset Rigid Barrier Strategy A: Absorb Energy	<u>233</u>
6.4.3	Small Offset Rigid Barrier Strategy B: Glance Off Barrier	<u>234</u>
6.5	Static Roof Crush	<u>239</u>
6.6	Note on Rear Impact	<u>241</u>
	References	<u>242</u>

CHAPTER 7

Design for Vibration	<u>245</u>
7.1 First-Order Vibration Modeling	<u>245</u>
7.2 Source-Path-Receiver Model of Vibration Systems	<u>249</u>
7.2.1 Automobile Vibration Spectrum	<u>251</u>
7.2.2 Human Response to Vibration	<u>252</u>
7.3 Frequency Response of a Single-Degree-of-Freedom System	<u>254</u>
7.3.1 Equation of Motion for SDOF System	<u>254</u>
7.3.2 Relation of Vibration Amplitudes	<u>256</u>
7.3.3 Regions of Vibration Behavior	<u>256</u>
7.3.4 Amplitude at Resonance	<u>257</u>
7.3.5 Transfer Function as Log-Log Plot	<u>259</u>
7.4 SDOF Models of Vehicle Vibration Systems	<u>260</u>
7.4.1 Powertrain Path: Reciprocating Unbalance	<u>260</u>
7.4.2 Suspension Path: Load at Spindle	<u>264</u>
7.4.3 Suspension Path: Deflection at Tire Patch	<u>270</u>
7.5 Strategies for Design for Vibration	<u>272</u>
7.5.1 Mode Map of Vehicle Vibratory Systems	<u>273</u>
7.6 Body Structure Vibration Testing	<u>273</u>
7.7 Modeling the Body Structure Resonant Behavior	<u>275</u>
7.7.1 Modal Model	<u>276</u>
7.8 Vibration at Frequencies above the Primary Structure Modes	<u>281</u>
7.8.1 Body Panel Vibration	<u>282</u>
7.8.2 Acoustic Cavity Resonance	<u>285</u>
7.8.3 Vibration Isolation through Elastomeric Elements	<u>287</u>
7.8.4 Local Stiffness Effect on Vibration Isolators	<u>294</u>
7.8.5 Summary: Design for Vibration	<u>295</u>
7.9 Note on Use of Rotating Phasors to Solve Damped Vibration Problems	<u>296</u>
7.10 Notes on Mechanical Impedance Technique	<u>298</u>
7.11 Note on Coupled Vibrations	<u>301</u>
References	<u>303</u>

CHAPTER 8**Vehicle Integration, Mass Estimation,
and Structure Layout 307**

8.1	Designing the Best Body Structure	<u>307</u>
8.2	Vehicle Layout	<u>308</u>
8.2.1	Side-View Vehicle Layout	<u>309</u>
8.2.2	Front-View Vehicle Layout	<u>313</u>
8.2.3	Plan-View Vehicle Layout	<u>316</u>
8.3	Exterior Body Surface	<u>317</u>
8.3.1	Basic Proportions for Styling	<u>317</u>
8.3.2	Aerodynamics	<u>319</u>
8.4	Constraints on Body Structure from Vehicle Layout and Exterior Surface	<u>321</u>
8.5	Preliminary Mass Estimation	<u>324</u>
8.5.1	Benchmark-Based Mass Estimation	<u>324</u>
8.5.2	Secondary Mass Change Model	<u>327</u>
8.5.3	Mass Compounding	<u>327</u>
8.5.4	Summary: Preliminary Mass Estimation	<u>331</u>
8.6	Body Structure Layout	<u>332</u>
8.6.1	Underbody Layout	<u>333</u>
8.6.2	Cross-Car Layouts	<u>338</u>
	Dash Layout	<u>338</u>
	Rigid Mounted Sub-Frame	<u>338</u>
	Rear Wheel House	<u>339</u>
8.6.3	Motor Compartment Layout	<u>340</u>
8.6.4	Rear Structure Layout	<u>345</u>
8.7	Summary	<u>349</u>
	References	<u>349</u>

CHAPTER 9**Material Selection in Preliminary Design 353**

9.1	Materials for the Body-in-White	<u>353</u>
9.1.1	Steel Grades and Aluminum Alloys	<u>353</u>
9.1.2	Alternative Materials for the Body-in-White	<u>355</u>
9.2	Method for Material Selection	<u>361</u>

9.3 Mass Benchmarking Alternative Materials	<u>370</u>
9.4 Summary: Material Selection	<u>371</u>
References	<u>371</u>
Appendix A: Exercises	<u>373</u>
Appendix B: Nomenclature	<u>419</u>
Appendix C: English and Metric Units and Typical Values for Key Parameters	<u>421</u>
Index	<u>423</u>