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Fabrication and Shipment Cracks in Prestressed Hollow-Core Slabs and Double Tees

prepared by

PCI Committee on Quality Control Performance Criteria

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Fabrication and Shipment Cracks in Prestressed Hollow-Core Slabs and Double Tees

prepared by

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CHAPTER 1 — INTRODUCTION

1. Purpose

This report is a catalogue of cracks which can occur in prestressed hollow-core slabs and double tees during the casting, stripping or shipment of the product. Some cracks can and do occur under service load, but this report is concerned with the fabrication and shipment process.

This report is intended to serve as a guide to identify typical cracks occurring in production and shipping of hollow-core slabs and double tees. The report can be utilized by the plant or production manager and quality control supervisor to identify casting, stripping or shipping cracks which can originate from numerous sources.

The plant engineer can employ the report to ascertain whether cracks are of a design or fabrication origin. Lastly, the designer can utilize the report to help him determine the causes and consequences of cracks and to assist him in making a judgment as to the acceptability of the product.

2. How the Report Was Developed

The report is based on a questionnaire distributed to Producer Members of the PCI who manufacture precast hollow-core slabs and double tees.

The questionnaire depicted different types of cracks and requested each respondent to list the causes, prevention and effect on serviceability. The replies were then synthesized by the Committee and put into the format of the report, a description of which follows.

3. How the Report Is Structured

The report is divided into two sections: Cracks in Hollow-Core Slabs and Cracks in Double Tees. Each crack is listed numerically and is given a generic name. A brief description of the crack appears under this title. The body of the report deals with the causes, prevention, effect and repair of the cracks. In the first column, the causes are described with an explanation, if required. The prevention is listed in the second column if it is not inherent in the cause. The last two columns cover consequences of the cracks and suggested methods of repair when required.

Daps, block-outs and notches are not covered in this report. These are special situations and in many cases they will require confinement reinforcement to function properly. Single tees are not mentioned specifically, but they are analogous to the double tees.

The report depicts hollow-core slabs with circular voided sections. All or most of the cracks described apply to hollow-core slabs with other shapes of voided sections.

4. Word of Caution

The designer or plant engineer should be made aware of any cracks which occur in order to be sure that the intended use of the member is not violated. This report has listed

the typical causes, preventions, and repairs of cracks, but it cannot be expected to anticipate every possible variation or extreme in requirements for design and serviceability.

Members which will be exposed to a corrosive environment are a special case; their integrity must be reviewed in this context. Epoxy can be utilized to repair and seal the visual cracks.

CHAPTER 2 — DEFINITIONS

Anneal: Heat strands prior to cutting to effect slower application of prestress.

Blocking. See Dunnage.

Bulkhead. See Header.

Crack: A continuous separation in the mass of the concrete with a visible displacement between the segments in one or more directions.

Debond: Any method used to prevent bond between strand and concrete.

Drape: Method whereby a straight strand is deflected to modify prestress eccentricity.

Dunnage: Shoring on which precast member is stored.

Hairline Crack: A continuous separation in the mass of the concrete but with a displacement measuring less than 0.004 in. (0.1 mm).

Harp: See Drape.

Heel: The horizontal surface at the end of the member, where it bears.

Header: The end form of a precast member, sometimes called a bulkhead.

Hold-Down Device: A mechanism used to hold down or drape strand.

Masking: A sheath placed around strand to prevent bonding of concrete.

Preset Time: Initial setting of concrete prior to applying curing.

Release: Detensioning of strand.

Rubber Void Forms: Inflatable forms for creating cores in hollow-core slab.

Shear Lag: The condition where flange width is large relative to its thickness and flange stresses are non-uniform due to flange distortion.

Spreader and Equalizer Beams: A beam used to spread the lifting cables to proper position for stripping precast members.

Stack Casting: A method where one member is cast on top of the other.

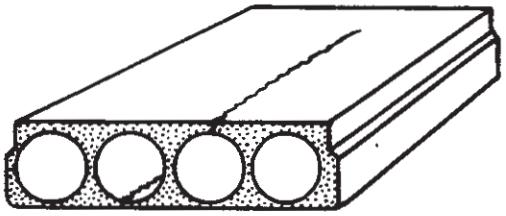
Transfer: Specifically, to transfer prestress force to the concrete. Also the initial stage of setting of concrete when it has not attained ultimate strength.

NOTE: A series of tables, depicting various types of cracking, causes, preventative measures, effects on serviceability, and possible repair procedures, begins on the following page.

CHAPTER 3 — CRACKS IN HOLLOW-CORE SLABS

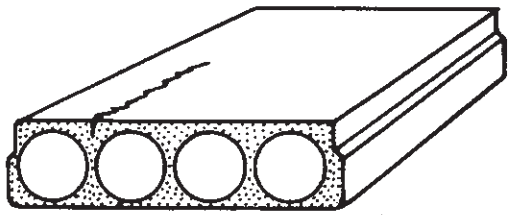
1. Longitudinal Crack at Void

Description — Longitudinal crack in either the top or bottom flange, or in both flanges at the end of the member.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Transverse shrinkage 1. Excess water in concrete	A. Proper mix and curing 1. Reduce water content.	Severe cracks such as a crack through the full depth of the member in an untopped system can affect load distribution where there are concentrated loads, openings, or transverse cantilevers.	Voids may be grouted solid or the crack may be epoxied. Repair may not be required especially if member is used in a topped system.
2. Rapid moisture loss	2. Cover product completely and as soon as possible (especially in windy, hot, or dry exposures). In extreme cases, spray product with mist or curing compound before covering.		
3. Heat applied too early	3. Increase preset time before curing temperature rise begins		
4. Excessive curing temperatures.	4. Reduce curing temperatures		
5. Differential in curing temperature side to side	5. Check for uneven curing temperature and make appropriate corrections		
B. Improper handling 1. Uneven dunnage	B. Proper handling 1. Use dunnage which provides uniform bearing		
2. Settlement of stack	2. Use heavier dunnage at bottom of stack to prevent settlement. Reduce height of stack		
C. Lack of or differential compaction	C. Improve vibration		
D. Placement and eccentricity of prestressing steel 1. Prestressing steel moved or displaced during casting	D. Proper positioning and design of prestressing steel 1. Exercise care during casting to prevent displacement of prestressing steel		
2. Imbalance of prestress force about vertical axis	2. Balance prestress about vertical axis, or minimize eccentricity		
3. Improper cutting sequence of prestressing steel	3. Cut prestressing strand symmetrically from center to outside		
E. Flange too thin due to movement or misalignment of void forms	E. Correct and maintain void form position		
F. Over-inflation of rubber void forms	F. Maintain proper inflation		

2. Longitudinal Crack at Web

Description — Longitudinal crack in top surface over the web. Cracks are not limited to ends of member, but can start and stop intermittently along the length of the member.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Subsidence over void 1. Excess water in concrete 2. Bleeding rubber void forms too soon	A. Prevent subsidence over void 1. Reduce water content 2. Delay bleeding of rubber void forms	Minor cracking should have little effect; however, it may create problems with concentrated load distribution in untopped system.	If crack is severe member may be cut to a narrower width or used in a topped system.
B. Shrinkage due to improper curing and mix proportions 1. Excess water in concrete 2. Rapid moisture loss	B. Improve curing procedures and mix 1. Reduce water content 2. Cover product completely and as soon as possible (especially in windy, hot, or dry exposures). In extreme cases, spray product with mist or curing compound before covering		
3. Heat applied too early	3. Increase preset time before curing temperature rise begins		
4. Excessive curing temperatures	4. Reduce curing temperatures		
5. Differential in curing	5. Check for uneven curing temperature and make appropriate corrections		

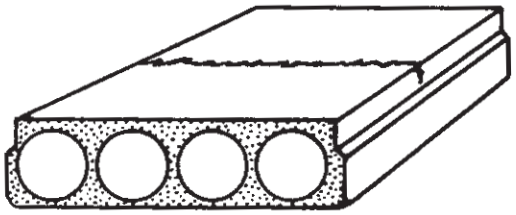
3. Transverse Crack

Description — Crack across the member, predominately occurs in the top, but can extend completely through the member in severe cases.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Longitudinal shrinkage 1. Excess water in concrete 2. Rapid moisture loss	A. Proper mix and curing 1. Reduce water content 2. Cover product completely and as soon as possible (especially in windy, hot or dry exposures). In extreme cases, spray product with mist or curing compound before covering	Potential shear capacity reduction if crack occurs at end. Can have a significant effect on shear and moment capacities of cantilevers. Reduction of moment of inertia in center of member can cause camber differentials and excessive deflections.	For minor cracks epoxy can be effective, and shear capacity can be increased by grouting voids solid at crack. Minor cracks in the top flange at areas of positive moment or in bottom flange at areas of negative moment may not require any repair. When a severe crack occurs in a member, cracked section should be cut out and resulting member placed in stock.
3. Heat applied too early	3. Increase preset time before curing temperature rise begins		
4. Excessive curing temperatures	4. Reduce curing temperatures		
5. Uneven heating along length of bed	5. Check heat distribution system		
B. Contraction due to delayed detensioning after uncovering heat cured product	B. Detension as soon as strength is verified, before product cools		

Continued on the next page . . .

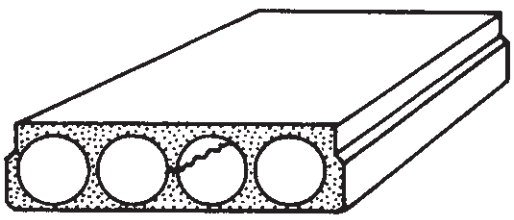
3. Transverse Crack *(continued)*

CAUSE	PREVENTION	
C. Excessive top fiber tension 1. Cantilever loading by misplacement of dunnage 2. Inadequate or misplaced tension reinforcement in cantilevers 3. Strand pattern too low 4. Low release strength	C. Reduce top fiber tension 1. Maintain proper dunnage location 2. Install adequate reinforcement at proper position 3. Check placement of strand and consider debonding at end of members 4. Increase release strength to accommodate top fiber tension	
D. Insufficient cover on transverse reinforcing bar (when required for special designs)	D. Increase reinforcing bar cover	

4. Web Crack Above the Strands

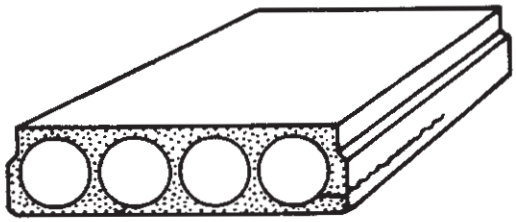
Description — A horizontal crack in one or more webs located above the strands. Crack widths can vary from hairline up to ¼ in. (6.3 mm) or more in severe cases.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Excessive prestress force relative to cross section of member	A. Reduce shear lag through webs 1. Increase web width or produce with solid voids 2. Debond strands at ends of members 3. Add top strands 4. Reinforce webs 5. Reduce prestress force if ultimate strength design controls and check service load requirements	Can reduce shear capacity because shear stress must be resisted by undamaged webs. Analysis should be conservative because shear failure is not ductile.	For minimal cracks epoxy may be effective, and shear capacity can be increased by grouting voids solid.
B. Insufficient release strength	B. Increase release strength		
C. Expansion of rubber void forms due to increased temperature	C. Bleed rubber void forms earlier		
D. Bottom surface of member sticking to form during stripping	D. Clean and oil form properly or ensure a dry contact surface when stack casting		
E. Saw-cut not deep enough	E. Cut completely through strands and as close as possible to the bottom of the member		
F. Lifting inserts or end stirrups misplaced	F. Place lifting inserts and stirrups properly		
G. Mix too wet or too dry	G. Adjust water content		
H. Insufficient vibration	H. Improve vibration		



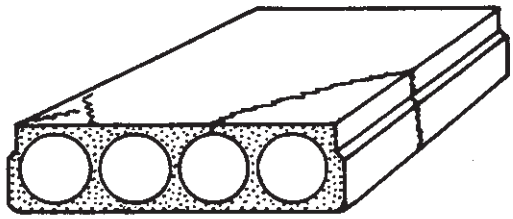
5. Web Crack at or Near the Strands

Description — Horizontal cracks in webs parallel to member length located at or near the strand.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Excessive bursting stresses 1. Web not thick enough for transfer of prestress force 2. Strand diameter too large for transfer through thin webs 3. Lateral strand drift 4. Low release strength	A. Reduce bursting stresses 1. Increase web width if possible 2. Provide equivalent prestress force with strands of smaller diameter 3. Check strand guides on machine 4. Increase release strength	Can reduce shear capacity because shear stress must be resisted by undamaged webs. Evaluation must include the effect of the associated strand slippage.	Repair of this member to account for the strand slippage which has occurred is not feasible; however, the shear capacity can be improved by grouting voids solid, or epoxying the cracks.
B. Lack of concrete consolidation around strands	B. Improve consolidation around strands		
C. Strand masking improperly placed	C. Secure masking to prevent movement		
D. Layers not bonded	D. Revise production procedures to avoid cold joints		
E. Saw-cut not deep enough or not complete across sides	E. Saw completely through or across member		

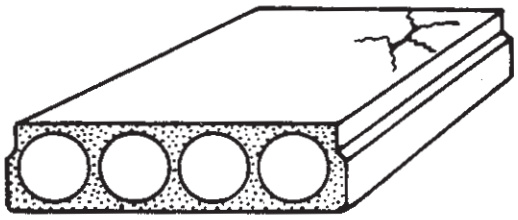
6. Corner Cracks

Description — Diagonal crack starting at the end of the slab possibly extending to the edge. May be in just the top or bottom flange, but could extend completely through the section.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Saw blade pinches when member cambers	A. Place weight on member to restrict camber	Usually minimal, but can reduce shear capacity if webs are damaged. Evaluated similar to opening occurring at the end of the member.	Cracks may not need to be repaired depending on shear requirements. Epoxy may be used on cracks. Voids may be grouted solid.
B. Saw-cut not deep enough	B. Cut completely through strands and as close as possible to the bottom of the member		
C. Saw blade "wobble" due to excessive use	C. Proper saw maintenance		
D. Uneven dunnage	D. Provide level supports		
E. Support blocks not providing even distribution of load during storage	E. Make sure support blocks do not transfer loads through flanges		
F. Uneven handling due to pick-up devices not being level	F. Use spreader beams to minimize uneven handling		
G. Excessive tension stress during stripping	G. Anneal strand and employ proper cutting sequence		

7. Miscellaneous Cracks

Description — Fine, shallow cracks in top surface of the slab occurring in a random pattern.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Surface shrinkage 1. Excess water in concrete 2. Rapid moisture loss	A. Proper mix and curing 1. Reduce water in concrete 2. Cover product completely and as soon as possible (especially in windy, hot or dry exposures). In extreme cases, spray product with mist or curing compound before covering. Use retarding admixtures.	Minor, but can be serious in a severe exposure situation.	None
3. Heat applied too early	3. Increase preset time before curing temperature rise begins		
4. Excessive curing temperatures	4. Reduce curing temperatures		
B. Improper troweling	B. Reduce troweling		
C. Improper mixes			
D. Improper operating of equipment			

CHAPTER 4 — CRACKS IN DOUBLE TEES

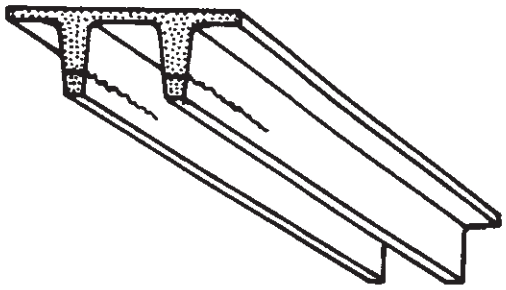
1. Horizontal End Crack in Stem

Description — This crack usually begins at the end of a double tee and extends horizontally for a distance of from several inches to a few feet. It is often located in the horizontal plane of a strand.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Improper design 1. Inadequate confining reinforcement 2. Excessive eccentricity 3. Excessive prestress force or concentration of prestress force	A. Improve design 1. Use adequate end reinforcement. 2. Be sure end stresses are within allowable limits. 3. Properly space and distribute strand at the ends of members.	If the plane of the crack coincides with a strand there is a possibility of loss of bond. This could reduce the shear and moment capacity of the member due to increased development length. If the plane of the crack does not coincide with a strand, the consequences are less severe. The end reaction does provide a clamping force for this type of crack.	If required, repair member using epoxy injection to prevent deterioration.
B. Improper release 1. Improper procedure for cutting strands 2. Low release strength 3. Slippage and impact from dirty strand 4. Improperly masked strand 5. Improper cutting sequence	B. Proper release 1. Anneal strand prior to cutting. 2. Achieve proper strength prior to releasing strand. 3. Keep strands clean. 4. Masking must allow for expansion and twisting of masked strands. 5. Keep prestress force balanced while cutting strands.		

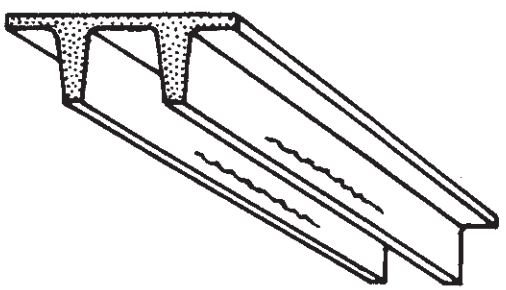
Continued on the next page . . .

1. Horizontal End Crack in Stem *(continued)*

CAUSES	PREVENTION	
C. Improper stripping and handling 1. Strand not completely cut 2. Strand caught in header 3. Improper header removal	C. Better stripping and handling techniques 1. Insure that all strands are fully cut. 2. Allow member to drift away from headers when lifting. 3. Separate header from concrete before lifting.	
D. Improper production 1. Indentations or joint offsets in forms 2. Excessive bleeding at headers 3. Improper end curing 4. Binding in forms	D. Improve production methods 1. Keep forms in good repair. 2. Replace damaged and worn out headers. 3. Prevent heat loss at headers. 4. Keep forms clean and properly oiled.	

2. Horizontal Crack in Stem

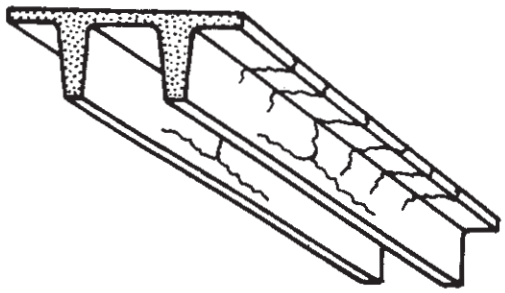
Description — This crack occurs at or between hold-down devices. If this crack branches upwards near its center it is probably caused by top fiber tension (see Crack 3). Absence of this vertical branch indicates that the horizontal crack is probably the result of vertical tensile stresses.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Excessive draping of strands. Vertical component of the prestressing force induces excessive tension.	A. Avoid draping too many strands at same hold-down and hold-up devices.	Hairline horizontal cracks are seldom serious. It is desirable to prevent cracks from growing.	Pressure inject with epoxy.
B. Improper stripping 1. Hold-down released prior to developing release strength 2. Hold-down not released before stripping 3. Member twisted during stripping causing it to bind in the form	B. Use proper stripping and handling techniques. 1. Do not release hold-downs until proper release strength has been attained. 2. Release hold-downs before lifting the member. 3. Keep the double tee transversely level when lifting.		
C. Improper production 1. Indentations in form 2. Binding in forms 3. Joint offsets in form	C. Improve production methods 1. Keep forms in good repair. 2. Keep forms clean and properly oiled. 3. Fabricate forms with even joints.		

3. Vertical Crack at Top of Member

Description — Crack starts at the top of the member and extends downward through the flange and into the stem. It is not uncommon for these cracks to fork horizontally when they reach the neutral axis.

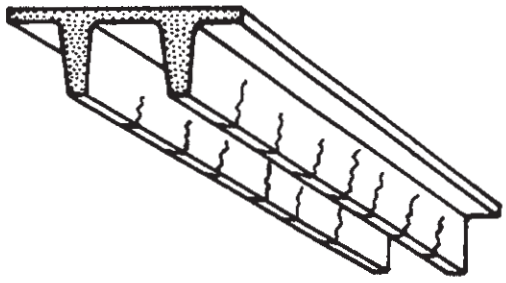
CAUSE	PREVENTION	EFFECT	REPAIR
A. Excessive cantilevers 1. Additional top fiber tension because of position of lifting points or dunnage 2. Top fiber tension at mid-span is too high because of reduced positive moment B. Excessive eccentricity due to draped or general position of strand results in excessive top fiber tension C. Vibration or harmonic motion when hauling on rough roads D. Hold-down device released prior to cutting strand (when vertical force component exceeds member weight)	A. Proper placement of dunnage and lifting points 1. Add negative reinforcement or use strand hold-ups. 2. Place dummy load at mid-span if temporary excessive cantilever is required. B. Check top fiber tension and do not over-depress strands. Place dummy load above hold-down devices when releasing. C. Check hauling procedures including: 1. Road conditions 2. Member length 3. Member design 4. Tie-down locations D. 1. Preferable method is: Increase release strength if required and provide dummy loads. 2. Alternate method is: Apply prestress force in stages by annealing strand prior to releasing hold-down. Protect heel if necessary.	These cracks are of little consequence in compressive areas, but they represent loss of stiffness in cantilevers.	Pressure inject with epoxy horizontal cracks in the stem and cracks in areas of negative moment.



4. Vertical Crack at Bottom of Stem

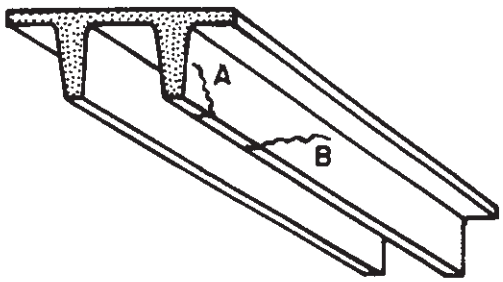
Description — These cracks are usually predominant and more closely spaced in areas of greatest positive moment.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Improper production 1. Indentations in form 2. Binding in forms 3. Joint offsets in form B. Improper storage or handling of members designed to be cantilevered C. Improper prestress 1. Strand location 2. Harping 3. Tensioning 4. Design 5. Losses underestimated D. Bond failure at end of member 1. Foreign matter on strands 2. Insufficient vibration E. Incomplete design	A. Improve production methods 1. Keep forms in good repair. 2. Keep forms clean and properly oiled. 3. Fabricate forms with even joints. B. Lift and support cantilever members as close to bearing points as possible. C. Verify that the correct prestressing force is being applied. 1. Check strands for correct location. 2. Check hold-down point for proper location and depth. 3. Compare measured strand elongation versus computed elongation. 4. Check design calculations for possible error. 5. Recompute losses. D. Prevent bond failures 1. Keep strands clean. 2. Vibrate properly. E. Consider erection stresses due to dynamic loads. Can be 25 to 50 percent of dead load.	If no bond failure has occurred at ends, the flexural strength is not affected. If strand slippage has occurred, check deflections based on a cracked section and reduced prestress. Member is not serviceable unless its capacity is verified by test or calculations. A reduced service load may be considered in some cases.	If the crack or cracks are due to either Cause A or B, then epoxy injection can restore the member to an uncracked section. If they are due to Causes C or D, then epoxy injection will have little or no effect.



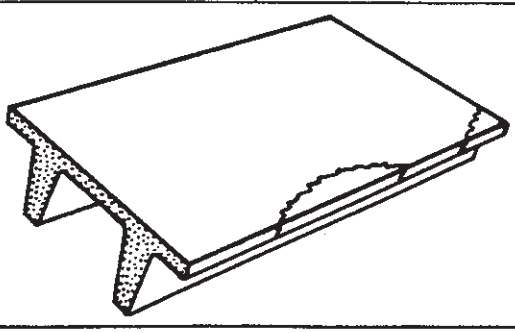
5. Diagonal Cracks in Stem

Description — These cracks usually begin near the bottom of the stem and progress diagonally upwards. Crack "A" extends towards the end and Crack "B" extends towards the center of the member.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Diagonal tension caused by sliding of member as prestress is released	A. Cut strands at each end simultaneously. Anneal if necessary.	Cracks crossing strands near the end of a member can be very serious because of the possibility of loss of bond between the end of the member and the crack as well as the increased transfer length beyond the crack. Shear is very much a problem unless member has stirrups or confining reinforcement.	Epoxy injection can restore the shear strength of the concrete if there is sufficient, bonded, positive reinforcement. Epoxy injection will not restore loss of bond or substitute for insufficient reinforcement.
B. Excessive bearing stress on heel of member as it cambers out of form	B. Use bearing plates or large chamfers at ends of stems. Check to see if confining reinforcement is required.		
C. Sudden expansion of form due to rapid heating	C. Allow temperature to rise slowly. Check to see if confining reinforcement is required. Consider lengthening preset time.		
D. Transverse movement of member while setting it down or dragging it sideways	D. Handle members carefully so that lateral forces are not applied to stems.		
E. Improper production 1. Indentations in form 2. Binding in forms 3. Joint offsets in form	E. Improve production methods 1. Keep forms in good repair. 2. Keep forms clean and properly oiled. 3. Fabricate forms with even joints.		

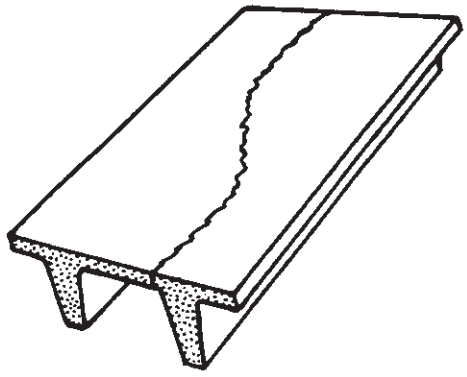
6. Flange Cracks Outside of Stems

Description — These cracks have the appearance of isolating a portion of the flange from the rest of the member.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Insufficient flange reinforcement or reinforcement in improper position	A. Use a sufficient mesh reinforcement in proper position.*	If mesh is too low, the capacity in the isolated area may be severely reduced. If mesh is in the proper location, these cracks will have virtually no effect upon the member's capacity unless vertical separation occurs. Roofing adhesive can seep through and contaminate exposed areas.	If a composite concrete topping is to be applied, just provide whatever shoring is necessary to support the concrete. If mesh is too low and no topping is to be used, added support must be provided. Epoxy injection or simply surface epoxy that only penetrates about ¼ in. (6.3 mm) will take care of seepage problem.
B. Binding at edge of form during stripping	B. Properly clean and oil edges of form.		
C. Bumping edges or corners when handling	C. Provide extra lateral reinforcement at the ends of the member.		
D. Improper dunnage transmits load to unsupported flange	D. Place dunnage properly.		
E. Binding mechanism bears against flange	E. Properly position binding mechanism.		
	*Refer to PCI JOURNAL, V. 21, No. 4, June 1976, p. 30 for recommended flange reinforcement.		

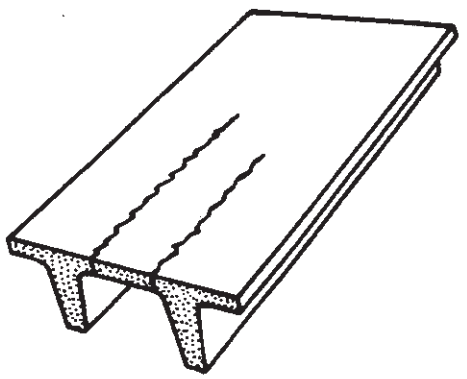
7. Flange Crack Between the Stems on Opposite Sides

Description — These cracks begin at opposite ends of the double tee flange and progress along the inside face of the stems crossing over to meet each other at the center of the member.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Torsional stresses due to twisting or racking of member 1. During stripping 2. During handling 3. During storage 4. During shipping	A. Employ handling techniques which will minimize twist. 1. Equalize lifting loads by making all lifting devices of equal projection, using proper spreader or equalizer beams, and/or sheaves. 2. Provide extra lateral reinforcement at ends of the member in the flange. 3. Employ level, rigid blocking. 4. When rough or uneven roads must be traveled, keep loads light with a low center of gravity and use a pivoting fifth wheel.	This type of crack usually has no effect upon the load carrying capacity. Roofing adhesive can seep through and contaminate exposed areas.	When a composite concrete topping is to be applied, no repair is necessary. Epoxy injection or simply surface epoxy that only penetrates about ¼ in. (6.3 mm) will take care of seepage problem.
			

8. Flange Cracks Each Side of Stem

Description — Longitudinal cracks that occur on each side of a stem and usually originate at the end of the member.

CAUSE	PREVENTION	EFFECT	REPAIR
A. Improper and incomplete consolidation B. Improper stripping so that member is tilted C. Volumetric change 1. Uneven curing 2. Uneven drying out 3. Heat curing too rapidly	A. Compact concrete properly. B. Lift member in level position so weight is not transferred to flange. C. Employ proper curing methods 1. Check heat distribution system. 2. Cover product completely and as soon as possible (especially in windy, hot or dry exposures). In extreme cases, spray member with mist or curing compound before covering. 3. Reduce rate of rise of curing temperatures.	This type of crack usually has no effect upon the load carrying capacity. Roofing adhesive can seep through and contaminate exposed areas.	When a composite concrete topping is to be applied, no repair is necessary. Epoxy injection or simply surface epoxy that only penetrates about ¼ in. (6.3 mm) will take care of seepage problem.
			

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