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쇄빙선 유체하중 해석을 위한 다면체격자 자동생성 알고리즘 개발

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An algorithm for automatic polyhedral grid generation for fluid load on ice breaker

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요 약

The grid generation is an essential process to analyze fluid load on ice breaker using computational fluid dynamics (CFD). However, it takes very many efforts and much time to generate quality grid. To reduce such efforts and time, various automatic grid generators are developed. However, almost automatic grid generator has difficulties with defining body shape exactly especially sharp edge. In this paper, an automatic grid generation algorithm based on octree refinement and cut-cell method is introduced. For fine grid arrangement around body boundary, the cells around body boundaries are refined by octree refinement algorithm. The body boundaries are defined by cut-cell method connecting the intersecting points between grid lines and body boundaries. However, the intersection points cannot define the sharp edges of bodies. To define the sharp edges, other intersecting points between grid faces and sharp edges are also defined and the intersecting points are added to body boundary faces. cut-cell method usually generates very small cells. such small cells are make the CFD solution unstable because of high Courant number. In this research, the short grid line, small grid face and small volume cells are removed by merging the grid points. The boundary layer grids are generated by extracting the body boundary faces in normal direction and grid points near the body boundary also moved. For continuous points movement, displacements of fluid cells are obtained by solving laplace equation.

Keywords : Grid generator(격자생성기), Polyhedral grid(다면체 격자), Octree refinement, Cut-Cell, Computational Fluid Dynamics(전산유체역학)

쇄빙선 유체하중 해석을 위한 다면체격자 자동생성 알고리즘 개발

2017년 대한조선학회 추계학술대회
2017년 11월 2일~3일
여수엑스포컨벤션센터

정광열, 한상헌
㈜ 넥스트폼

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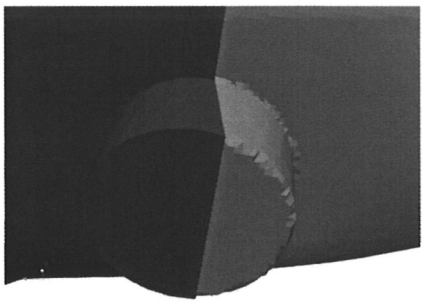
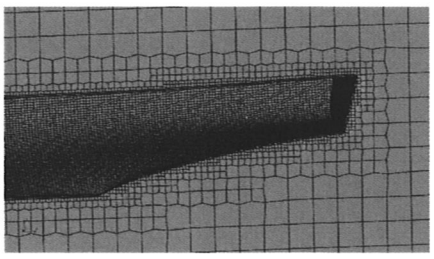
연구배경 및 목표

➢ 연구배경

- 격자생성에 과도한 시간과 노력이 필요
  - 격자를 쉽게 작성하기 위한 연구가 진행
    - Immersed Boundary Method
    - Particle method (SPH/MPI)
    - 격자 자동생성 알고리즘
- Hexahedral 격자 기반의 자동격자생성 프로그램이 개발됨
  - Star-CCM+의 trimmer mesh
    - 물체형상 표현이 정확하고 효율적인 격자 배치가 가능
  - snappyHexMesh
    - 물체형상을 정확히 표현하지 못하는 경우가 자주 발생
  - cfMesh
    - 정육면체기반으로 작성되어 효율성이 낮음





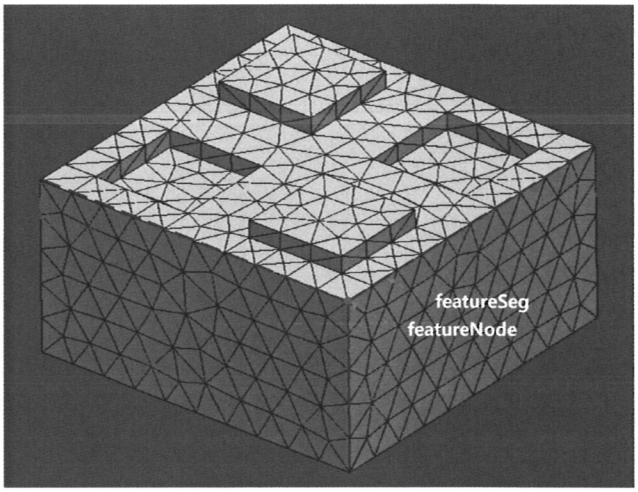
➢ 연구목표

- Hexahedral 기반의 자동 격자생성 알고리즘 개발
  - 정육면체 뿐만 아니라 모든 육면체 격자의 분할
  - 물체형상을 정확하게 구현

용어의 정의

➢ 물체의 형상 (STL)

- Element, Segment, Node
- Feature Segment
  - Element간의 각도가 크거나, patch가 다른 element가 공유하는 edge
- Feature Node
  - 3개 이상의 feature segment가 만나는 node



➢ 격자계

- Cell, Face, Edge, Point
- Feature edge
  - Feature segment에 의하여 생성된 edge
- Feature point
  - Feature node에 의하여 생성된 point

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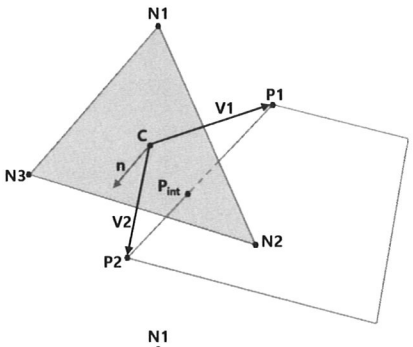
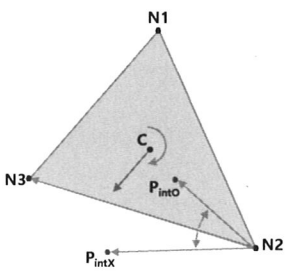
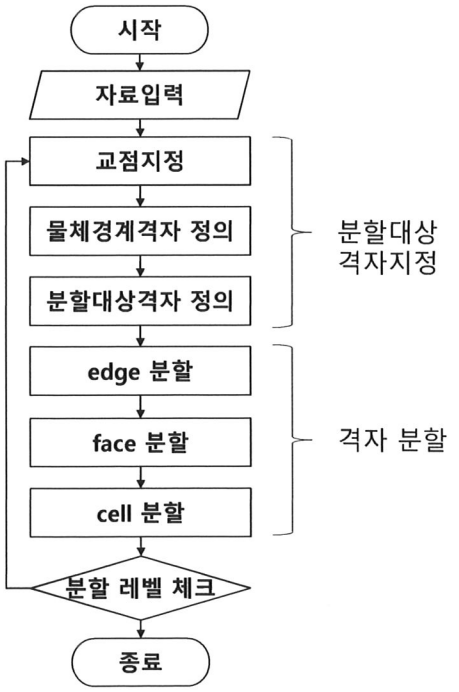
격자의 분할

➢ 분할 대상 격자의 지정

- 물체면과 격자선의 교점을 포함하는 격자를 분할 대상 격자로 지정
- 격자선과 물체면의 교점 탐색
  - 직선과 평면의 방정식으로 교점 정의







격자분할 순서도

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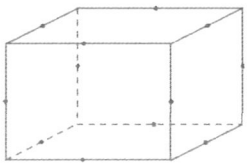
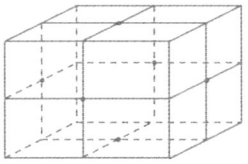
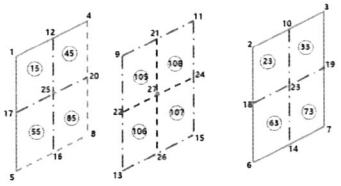
➢ 격자의 분할

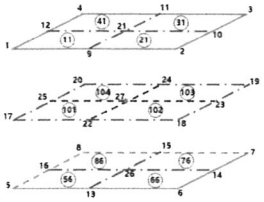
- Edge 분할
  - Face : 6
  - Edge : 8 → 16
  - Point : 8 → 20



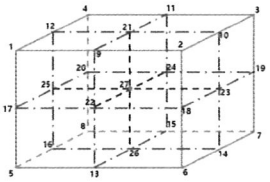
- Face 분할
  - Face : 6 → 24
  - Edge : 16 → 48
  - Point : 20 → 26

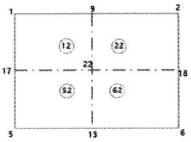


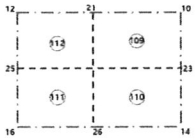


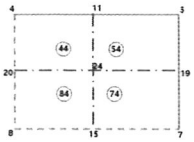


- Cell 중심점 추가
  - Face : 24 → 36
  - Edge : 48 → 54
  - Point : 26 → 27

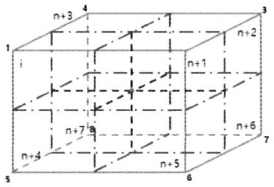








- Cell 분할
  - Cell : 1 → 8



물체의 형상 정의

➢ 교점의 정의

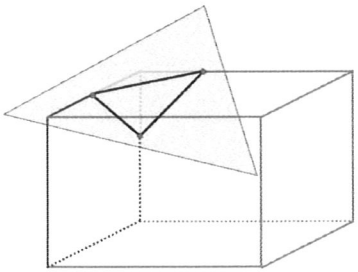
- 격자의 분할 과정의 교점 정의와 동일

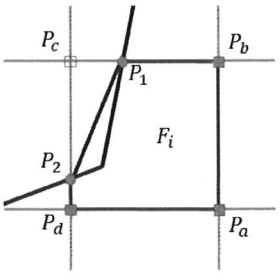
➢ Edge Cut

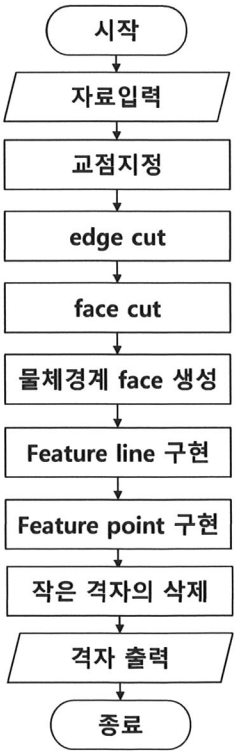
- 교점 P_1으로 edge(P_bP_c)를 분할
  - $P_bP_c \rightarrow P_bP_1+P_1P_c$
- 교점을 face 구성 point에 추가
  - $F_i = (P_a, P_b, P_c, P_d) \rightarrow F_i = (P_a, P_b, P_1, P_c, P_2, P_d)$

➢ Face cut

- Face의 구성 point 중 물체 내부 point는 삭제
  - $F_i = (P_a, P_b, P_1, P_c, P_2, P_d) \rightarrow F_i = (P_a, P_b, P_1, P_2, P_d)$
- Face를 구성하는 point의 수가 '0'인 face는 삭제
  - Cell을 구성하는 face 정보도 수정

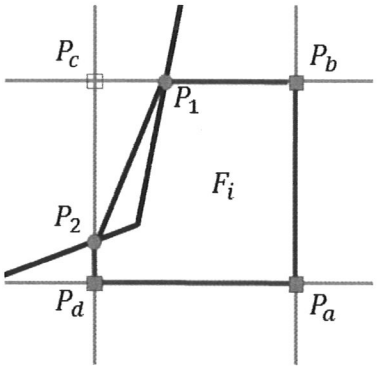


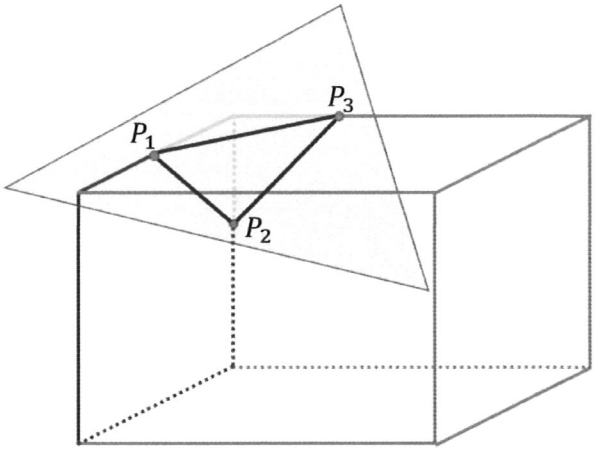




➢ 물체경계 face의 생성

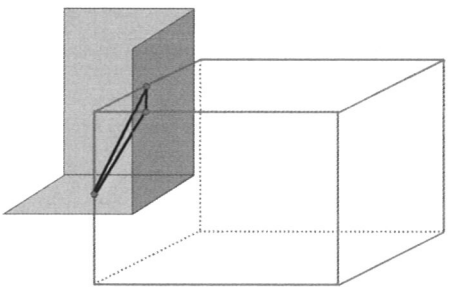
- Cell을 구성하는 face 중 교점으로 구성된 edge 를 탐색
  - 아래의 그림의 경우 3개의 face에 3개의 segment가 존재
  - (P_1P_2), (P_2P_3), (P_3P_1)
- 탐색된 edge들을 이용하여 face 생성
  - $F_b = (P_1, P_2, P_3)$

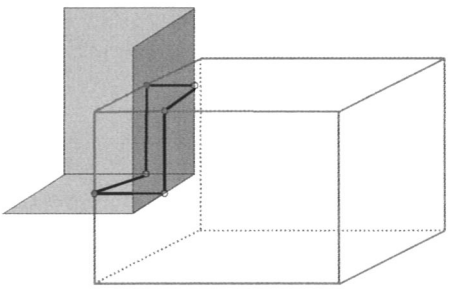


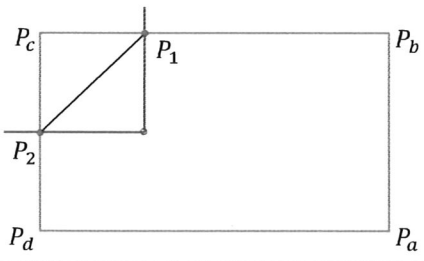


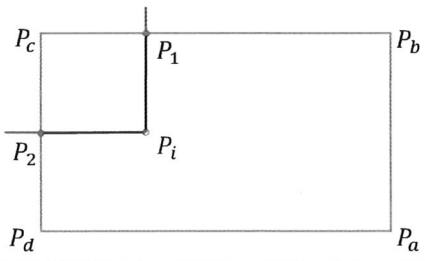
➢ Feature line 구현

- Feature segment와 face의 교점을 정의
- Feature segment와 face의 교점을 face 구성 point로 추가
  - $F_i = (P_a, P_b, P_1, P_2, P_d) \rightarrow F_i = (P_a, P_b, P_1, P_i, P_2, P_d)$
  - $F_b = (P_1, P_2P_3) \rightarrow F_b = (P_1, P_iP_2P_j, P_3P_k)$



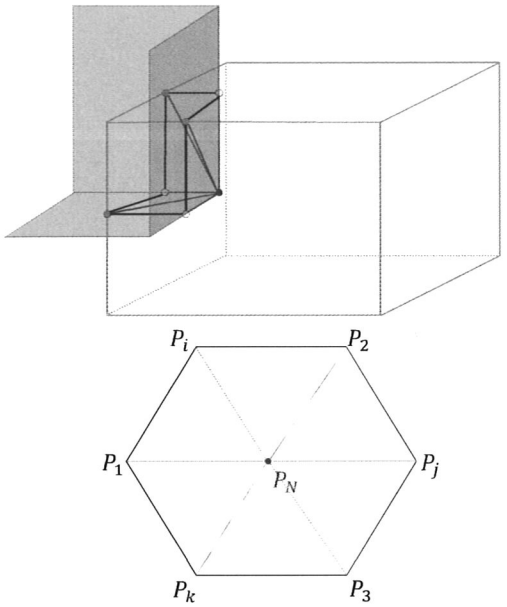


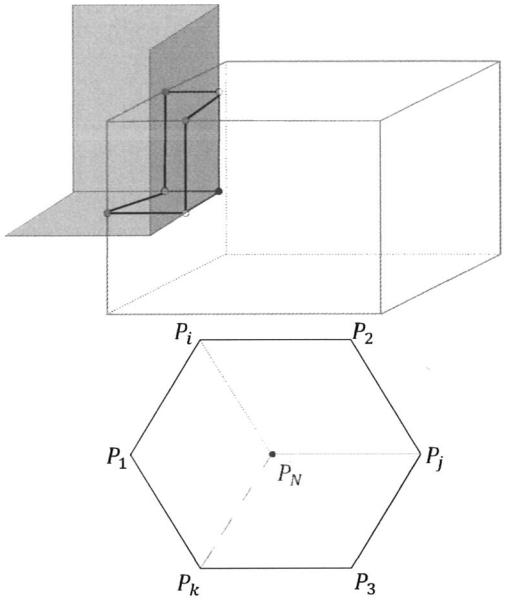




➢ Feature point 구현

- Feature node를 중심점으로 물체경계면을 삼각형으로 분할
- 이웃한 삼각형 face간의 각도가 작은 경우 병합





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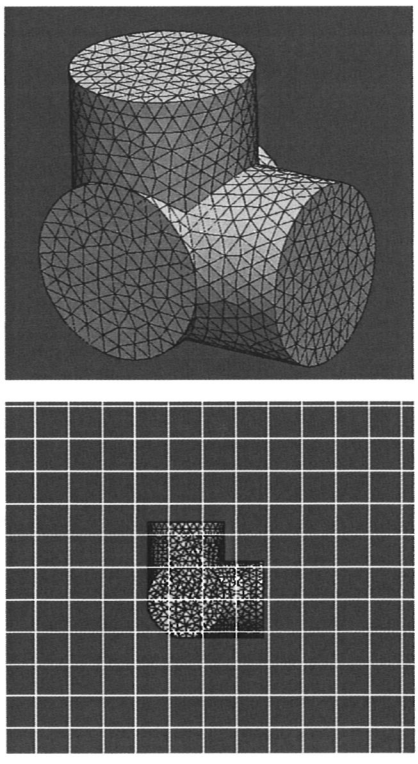
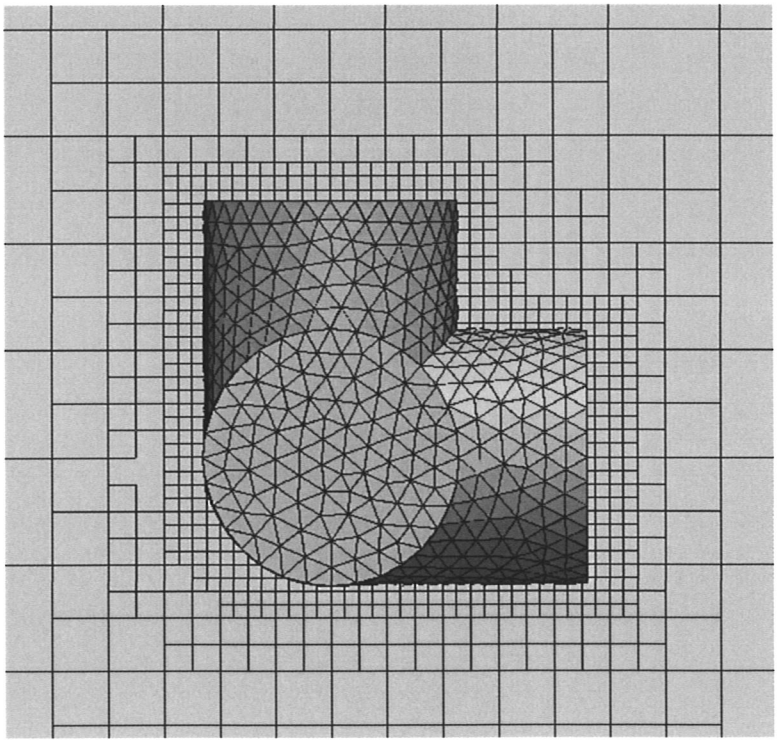
Example 1





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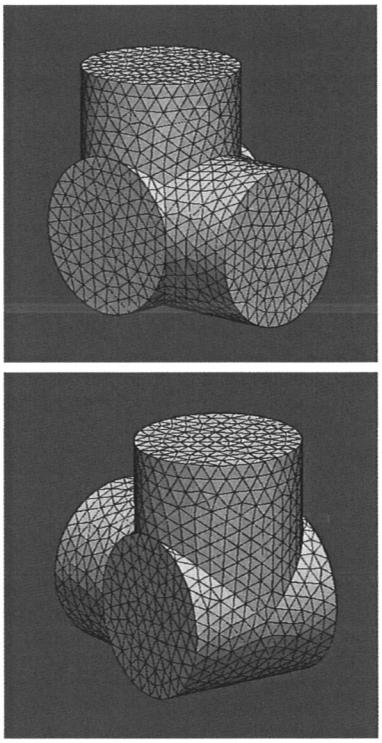
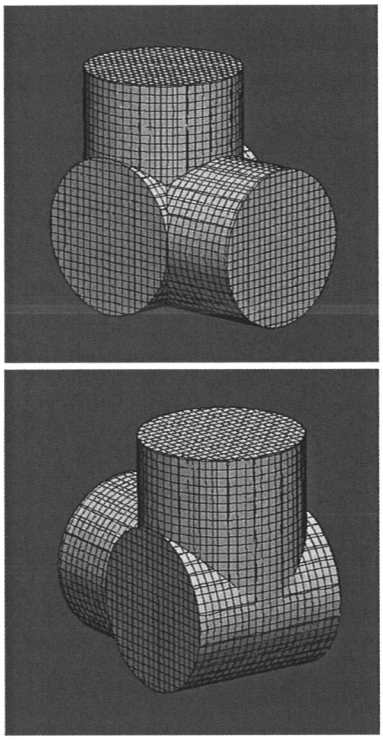
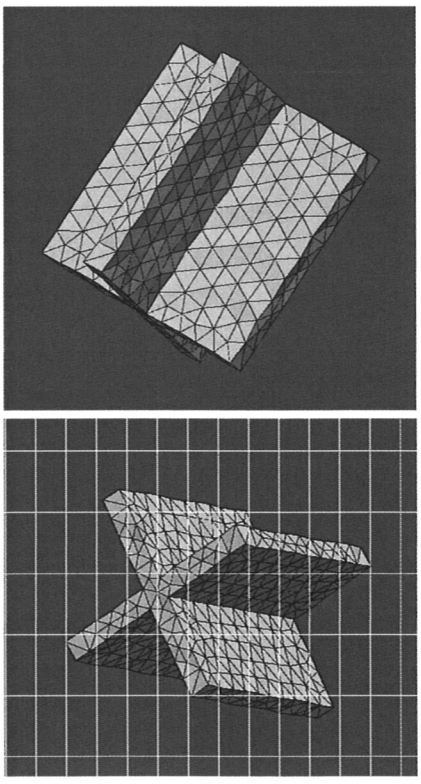


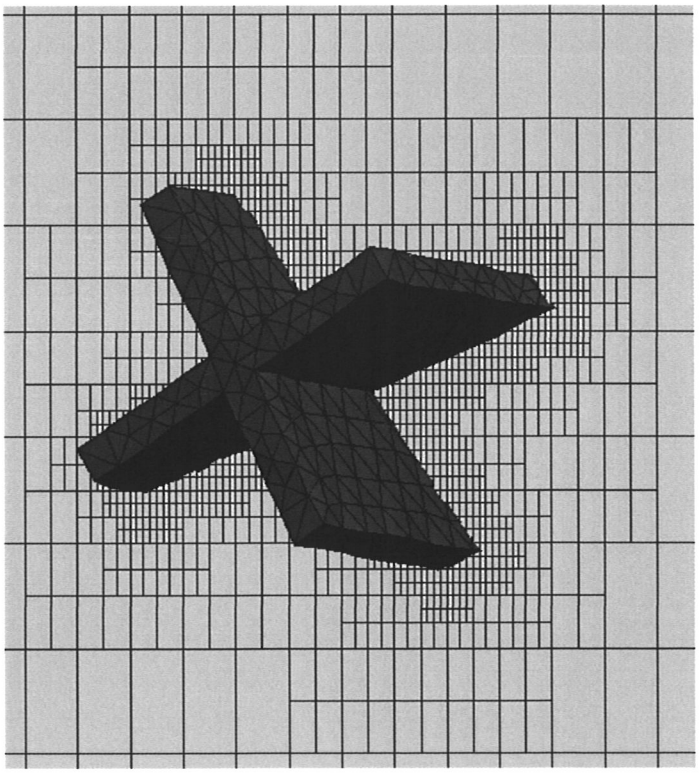
물체 형상

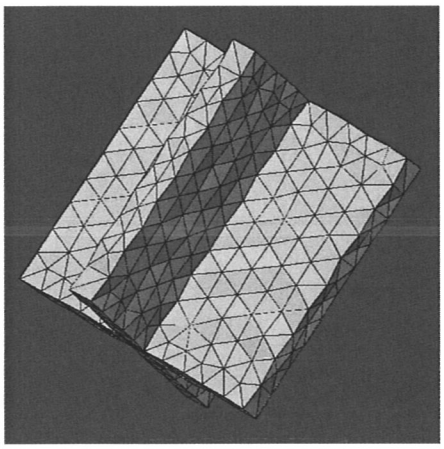


물체경계면

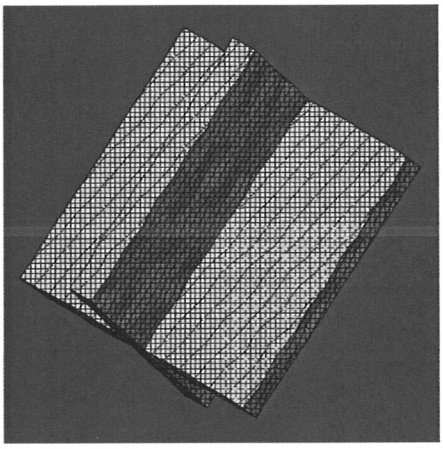
Example 2



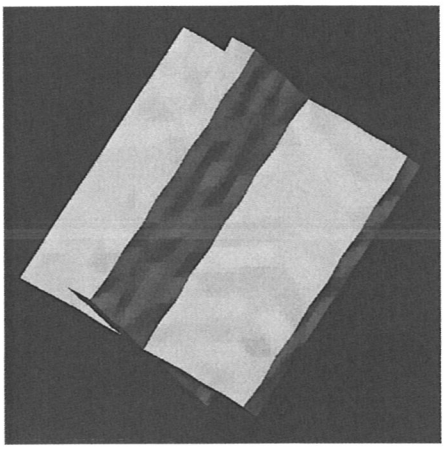




물체 형상



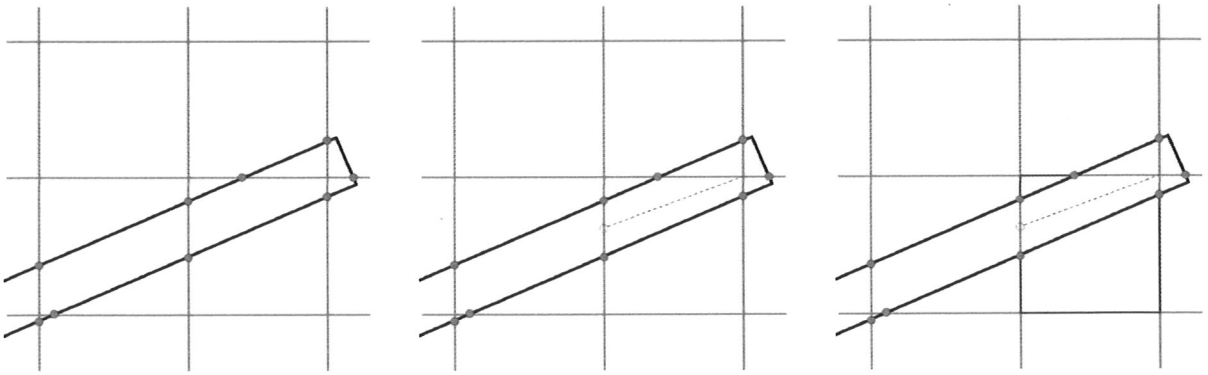
물체경계면

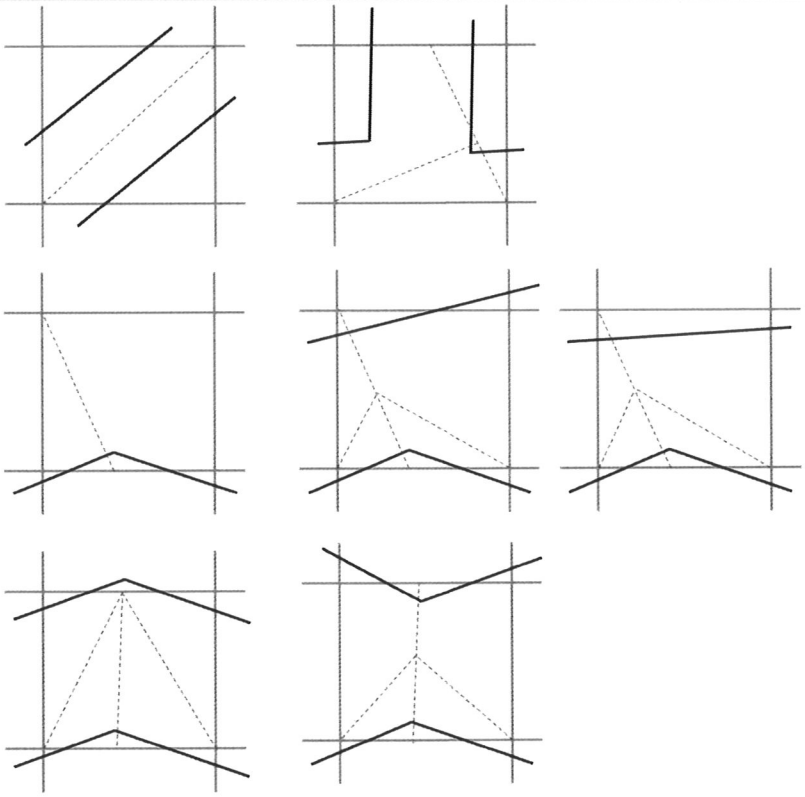


물체경계면

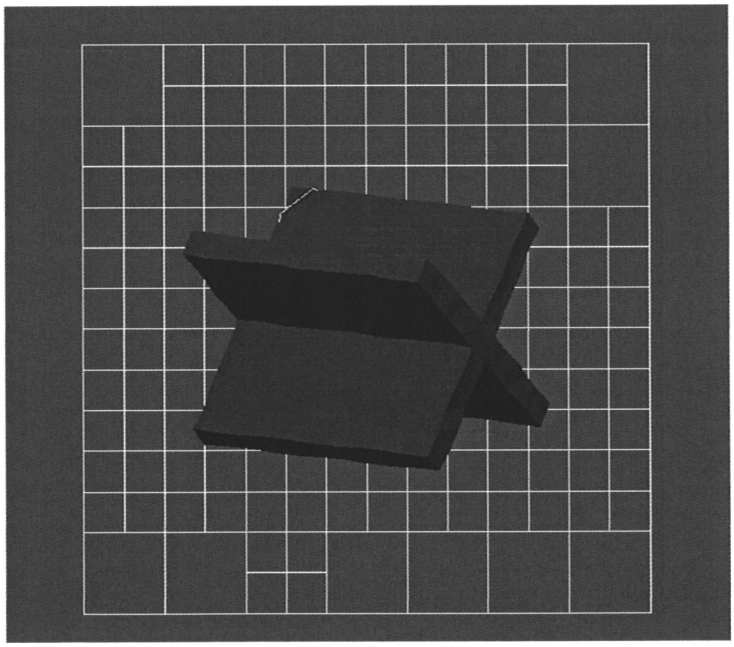
얇은 물체의 처리

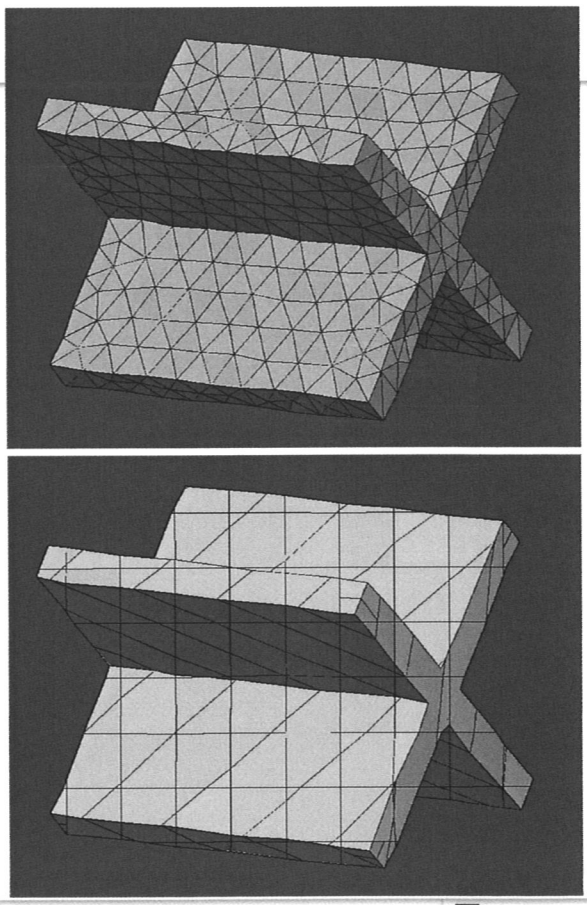
- **물체가 얇은 경우 하나의 격자면이 2개 이상으로 분리됨**
- **격자면을 물체형상 정의 전에 격자면을 미리 분할**





Example 3

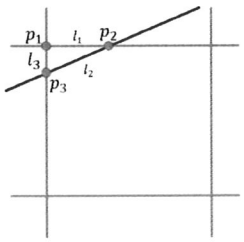


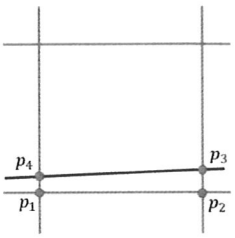


작은 격자의 처리

➢ **면적이 작은 격자면**

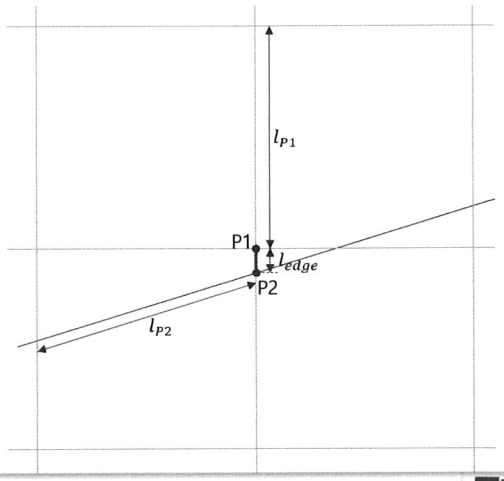
- **삼각형**
  - 두 개의 점을 나머지 점으로 이동 시켜 통합
    이동거리가 가장 짧은 점을 선택
- **사각형**
  - 가장 긴 격자선을 선정 (두 개의 점을 선택)
  - 선택되지 않은 점들을 가까운 점으로 이동





➢ **짧은 격자선**

- **각 점에 연결된 최장 선분을 저장**
  - $l_{P1}<l_{P2}$: P1을 P2로 이동
  - $l_{P2}<l_{P1}$: P2를 P1으로 이동



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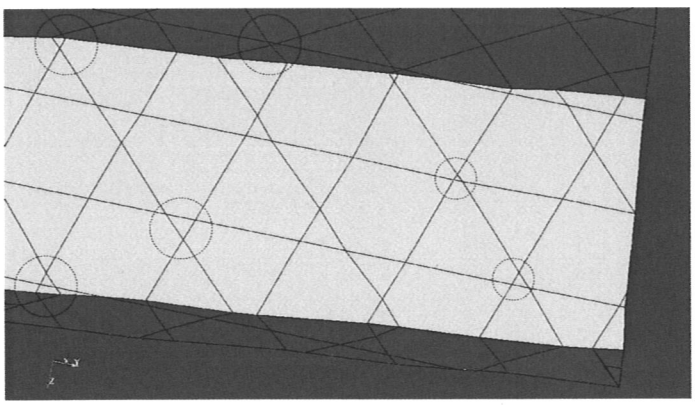
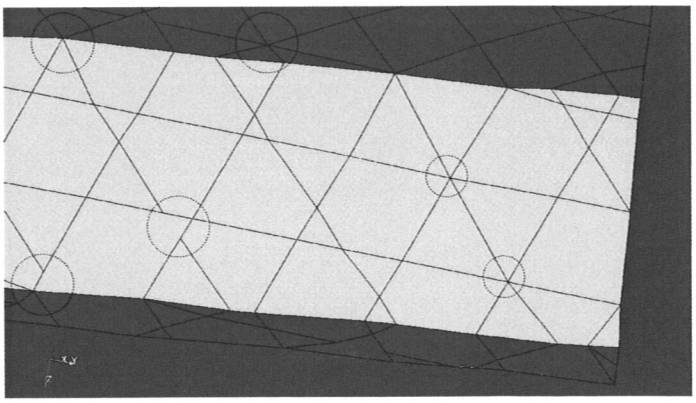
Example 4





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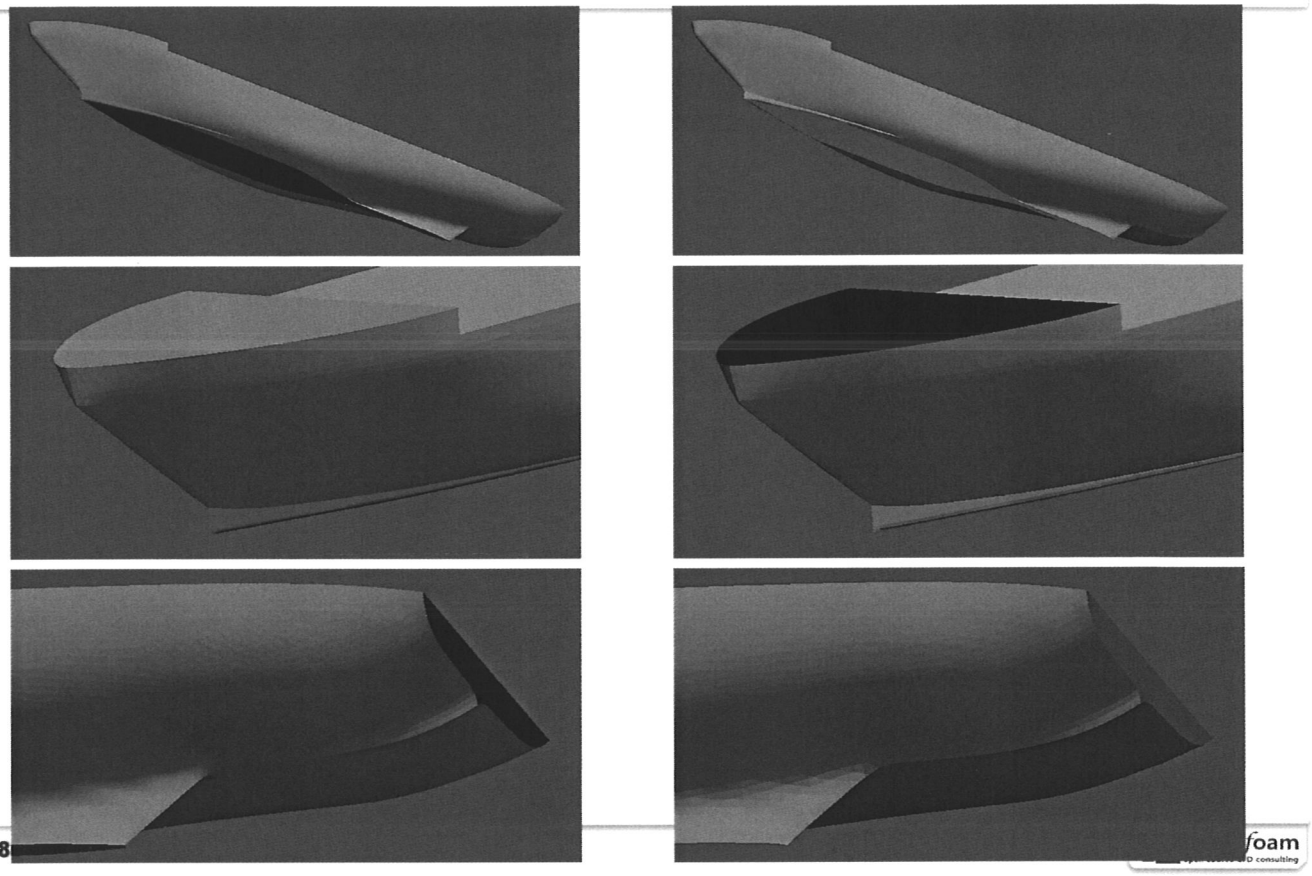
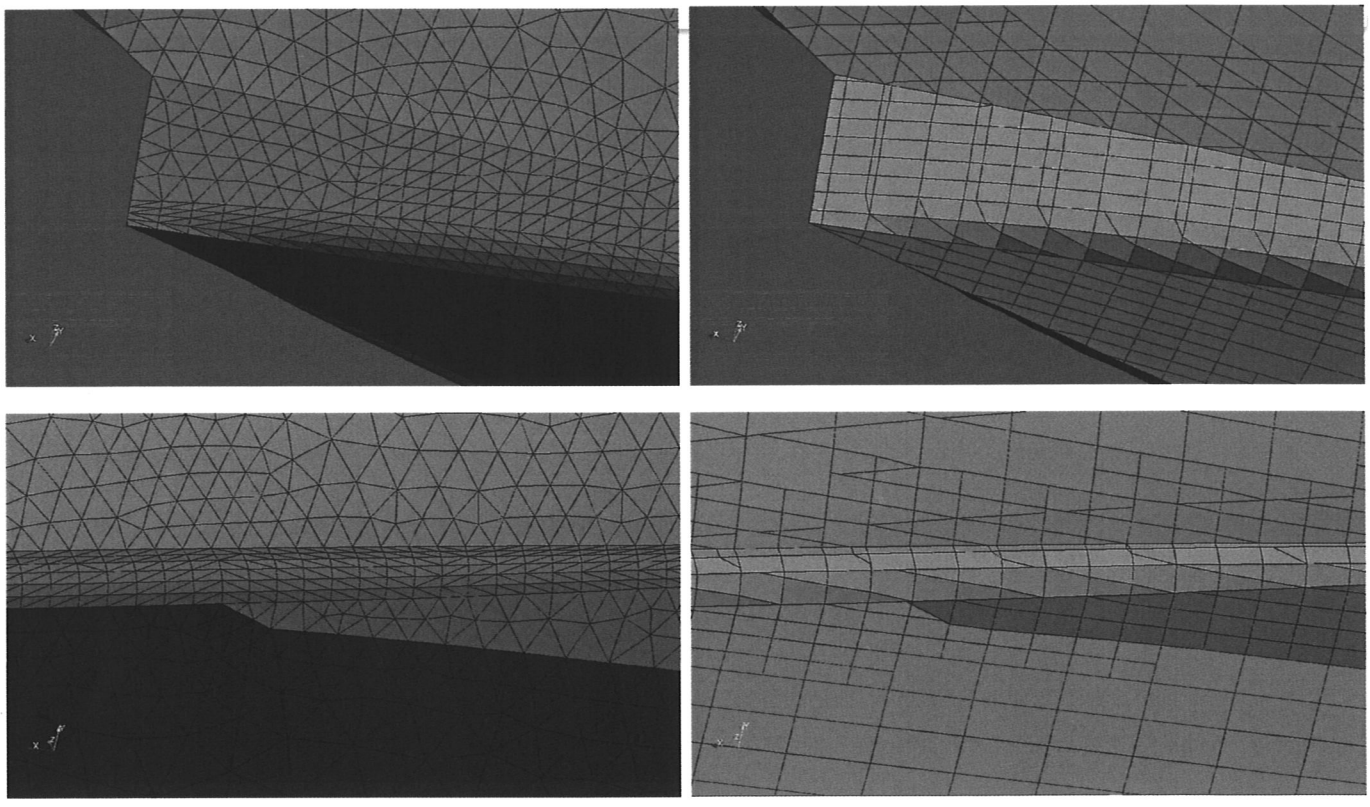
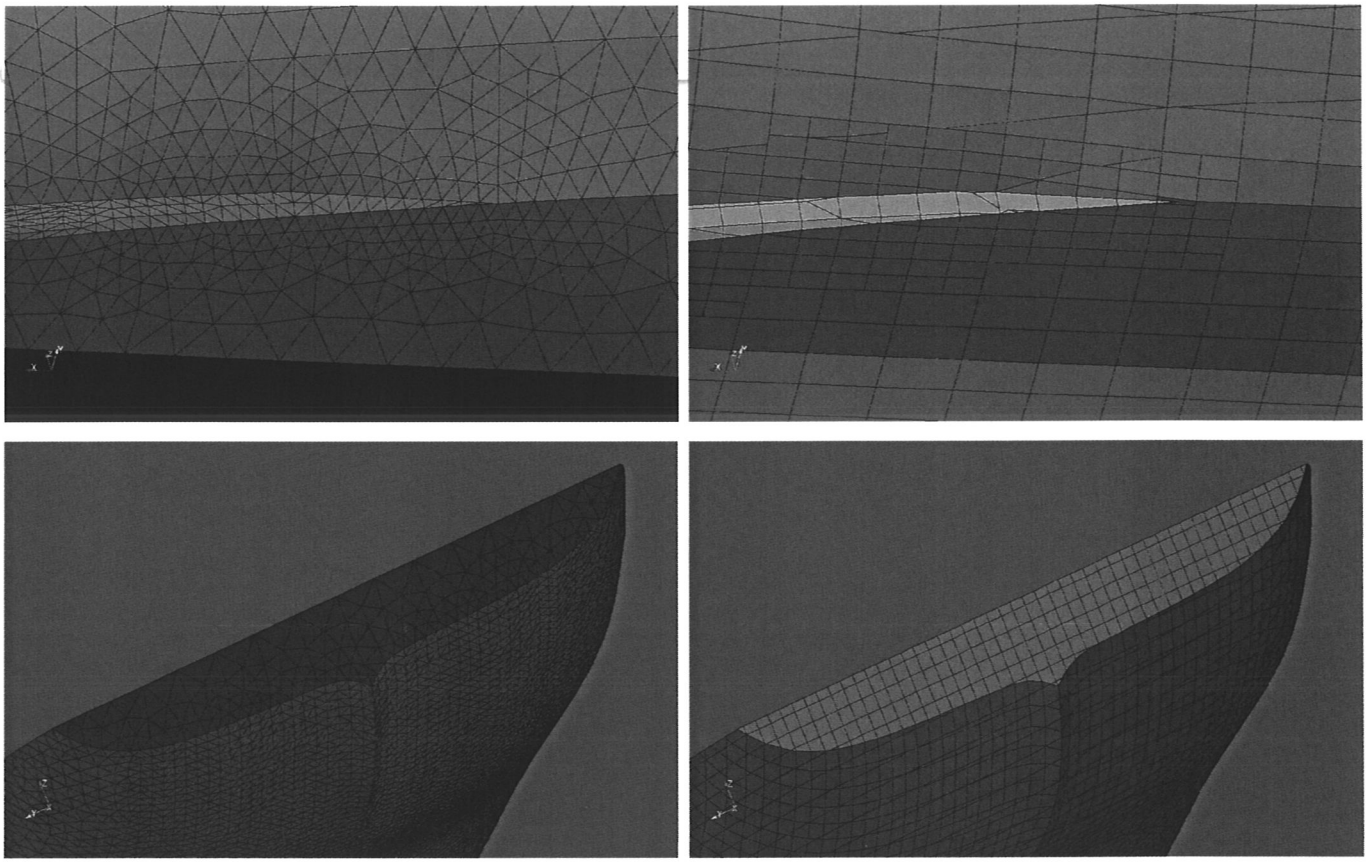
Example 5



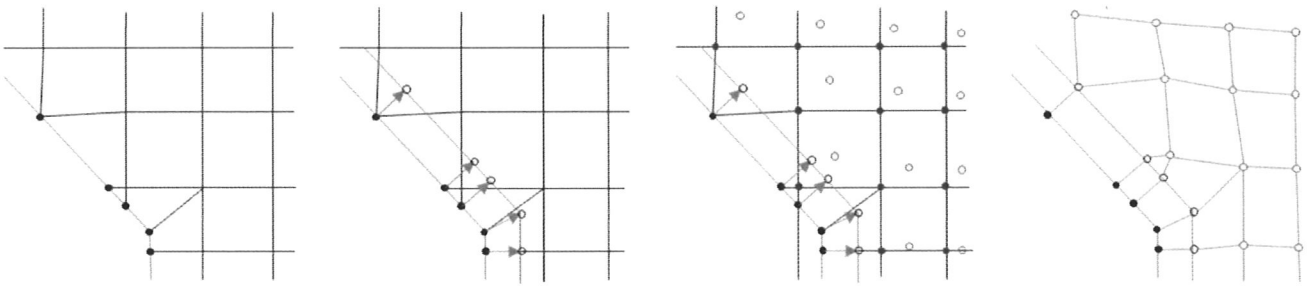




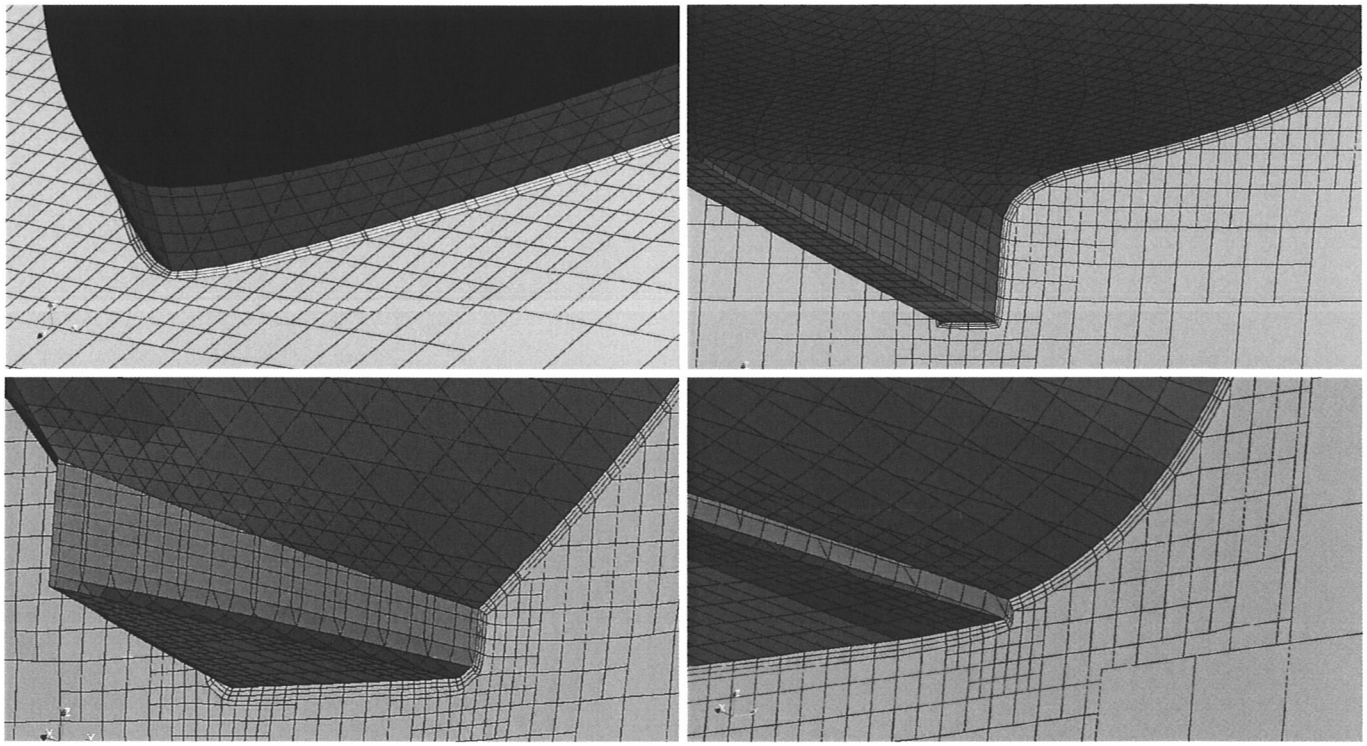
경계층 격자의 생성

- **경계면의 격자점을 수직한 방향으로 복사생성**
- **경계층 격자의 두께에 따라 주변의 격자점을 이동**
  - 라플라스 방정식을 계산하여 이동량을 결정
  - 확산계수는 거리의 역수로 설정

$$\nabla \cdot \left(\Gamma \nabla \vec{R}\right) = 0$$



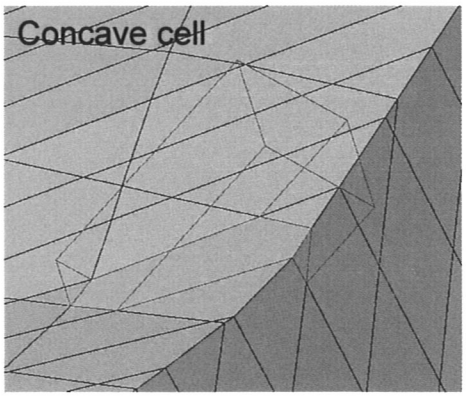
Example 6



결론 및 향후 연구

➢ 결론

- 쇄빙선 유체하중 해석을 위한 다면체 격자 자동 생성 알고리즘 개발
  - 임의의 육면체 격자에서 격자 분할 가능
  - 선형을 정확히 구현 가능
- 선박 뿐만 아니라 다양한 분야에 적용가능



➢ 향후 연구

- Concave 격자의 처리 기법 개발
- 선형 곡률에 따른 격자분할 레벨 자동지정 기술 개발
- Kelvin 파 예측을 통한 격자분할 레벨 자동지정 기술 개발
- 첫 번째 경계층 격자 두께 자동 계산 기술 개발