

RESPONSE OF SHIP STRUCTURES SUBJECTED TO UNDERWATER EXPLOSION

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**DEPARTMENT OF APPLIED MECHANICS
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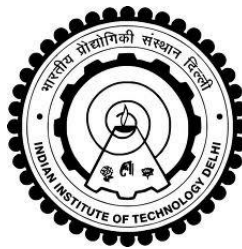
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CERTIFICATE

This is to certify that the thesis titled “**Response of Ship Structure to Underwater Explosion**” being submitted by **S Koteswar Rao** to the Indian Institute of Technology, Delhi for the award of Degree of Doctor of Philosophy is a record of bona-fide research work carried out by him. S Koteswar Rao has worked under our supervision and guidance and has fulfilled the requisites for the submission of this thesis which has reached the requisite standard for the Doctor of Philosophy Degree. The results contained in this thesis have not been submitted in part or full, to any other university or institute for the award of any Degree or Diploma.

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ABSTRACT

The idea of using the explosive charges underwater to damage and sink the targets at sea has been there since the days of early Marine warfare, although the effective means to do it were limited or did not exist. According to the analysis of the wartime ship losses suffered during the first half of the twentieth century, it was determined that the incident shock wave and explosion gas bubble pulse forces caused severe structural damage and material failure, and resulted in the sinking of several ships.

In spite of significant efforts by various agencies like government, military and civil resources directed towards mitigating the vulnerability of humans and structures due to the blast effects, it is widely accepted that the effects of the Underwater Explosions (Undex) is still poorly understood. Moreover, the knowledge is not in public domain due to strategic reasons and hence not available to us. It is therefore of significance that theories and models capable of describing the phenomenon and its effects be developed to describe/understand the events qualitatively and quantitatively.

Underwater explosions, generally referred to as UNDEX, occurring in the water near the ship hull are of great concern to naval surface ships and submarines since they can result in major hull damage or incapacitate their functionality. Analyzing this phenomenon requires understanding a complex sequence of events, shock wave propagation, cavitation and fluid-structure interaction phenomena. Study of this phenomenon is very limited in the country forcing us to largely seek guidance from abroad, which is costly and may be unreliable in the long term. The present study is restricted to numerical analysis as the experimental set up is not only unavailable but exorbitantly costly in terms of monetary and environmental terms. Further, the cost and associated risks are far too many. Presently, an effort is made to use FEM (Abaqus explicit) to accurately model the loads, fluid-structure interaction and the propagation of stress/strain to the structure. Once, the numerical model is successfully validated with the available experimental results, a parametric analysis is carried out. The study is extended to the failure state of the plates

post deformation and the initiation of tearing and their location is understood. The source of initiation and its location is paramount for underwater vehicle as it will lead to flooding and subsequent loss of the platform.

The evaluation of the failure of the plates subjected to undex, qualitatively confirmed the various modes of failure postulated by researchers. The mode I failure representing large deformation at which the subject structure would fail to undertake its function, effectively. The second failure mode or mode II failure is denoted by the tearing of the edges which is found to be initiating at the centre and then move on to the end of the clamped edges. Further increase in the load led to initiation of mode III failure which is rupture of the plates. The behaviour of Stiffened plates when subjected to Undex is also studied to compare their efficacy over an equivalent flat plate. As expected, the stiffened plates offer greater rigidity by resisting bending. As most of the underwater structures are stiffened, the study represents generally found structural configurations. The stiffened plates are found to be more effective in withstanding the undex loads when compared relative to an equivalent solid plate of equal mass. The deformation profiles are also found for various loads. It is also found that the response of such simple structure can also be represented by numerical equations to a reasonable extent and the same will help in deducing the optimum strength required to withstand a known undex loading.

The numerical study is extended to honeycomb sandwich structures where a honey comb core is sandwiched between two flat plates, such structures are found to be of use in absorbing explosion energy and thereby protecting the structure underneath. The face plate is exposed to the blast load and the benefits accrued in terms of reduced deflections of back plate are studied. Comparison with equivalent solid plate of equal mass are undertaken. The benefits of a sandwich panel construction over a solid plate to withstand blast loads are clearly evident by the lower back plate deflections compared with, the equivalent weight solid plates subjected to the same impulse loading. The progress of impact or blast loading is seen from that of significant front face bending and progressive cell wall buckling at the centre of the panel closest to the source of explosion to that of bending and stretching of back plate. Further, it was found that the bending and stretching deformations progress from the clamped boundaries to the centre and

stretching generally is found to influence the final shape. Change of boundary conditions is found to increase back plate deflections but has no role in core crushing as compared to clamped conditions. The cell wall buckling and core densification increased as the impulse is increased. Further, the benefits of sandwich structures are evident only with the intact cores and the diminishing returns as the core crushing begins. Hence, identifying suitable combination panel is crucial to gain advantage over equivalent solid plates. Investigation into various different types of cores and their collapse mechanism will give us greater insight towards defending an explosive load.

The estimation of behaviour of structures in order to optimise structures and to find suitable configuration that can withstand Undex loads using numerical analysis is an innovative approach to obviate the limitation of experimental means as explained earlier. The numerical analysis is done using commercially available FEM package Abaqus.

सार

समुद्र में लक्ष्य को नुकसान पहुंचाने और डुबोने के लिए पानी के नीचे विस्फोटक आरोपों का उपयोग करने का विचार समुद्री युद्ध के शुरुआती दिनों से ही रहा है, हालांकि इसे करने का प्रभावी माध्यम सीमित था या अस्तित्व में नहीं था। इसने घटना को समझने, प्रभावों का अध्ययन करने और डिजाइन संरचनाओं के बदले में इस तरह की उच्च तीव्रता गतिशील भार से संरक्षित किया जा सकता है।

अंडरवाटर विस्फोट, जिसे आम तौर पर यूएनडीएक्स कहा जाता है, जहाज के पतले के पास पानी में होने वाली नौसेना के सतह जहाजों और पनडुब्बियों के लिए बहुत बड़ी चिंता होती है क्योंकि इससे बड़े पैमाने पर नुकसान हो सकता है या उनकी कार्यक्षमता में असमर्थता हो सकती है। इस घटना का विश्लेषण करने के लिए घटनाओं, सदमे की लहर प्रसार, पोकेशन और द्रव-संरचना इंटरैक्शन घटनाओं के जटिल अनुक्रम को समझने की आवश्यकता है। पानी के नीचे विस्फोटों को दो श्रेणियों में वर्गीकृत किया जा सकता है। पानी के नीचे विस्फोट से संपर्क करें, जहाज के पतवार के संपर्क में या उसके संपर्क में पानी, जैसे प्रभाव-फ्र्यूज्ड टारपीडो हिट या संपर्क खान के विस्फोट के साथ होता है। इन विस्फोटों के परिणामस्वरूप पतवार को गंभीर स्थानीय क्षति हुई। दूसरा प्रकार, गैर-संपर्क पानी के नीचे विस्फोट, जहाज के जहाज से दी गई दूरी पर जहाज के ढेर के संपर्क में नहीं होता है। एचबीएक्स -1, आरडीएक्स, टीएनटी और पीईटीएन जैसे उच्च विस्फोटक शामिल गहराई के आरोपों का विस्फोट गैर-संपर्क पानी के विस्फोटों का एक उदाहरण है। अंडेक्स घटनाओं के परिणामस्वरूप जहाजों और उनकी कार्यक्षमता के लिए सबसे गंभीर और गंभीर सदमे की क्षति होती है।

अंडेक्स के अधीन प्लेटों की विफलता का मूल्यांकन, गुणात्मक रूप से शोधकर्ताओं द्वारा नियत विफलता के विभिन्न तरीकों की पुष्टि की। मोड I विफलता बड़े विरूपण का प्रतिनिधित्व करती है जिस पर विषय संरचना प्रभावी ढंग से अपना कार्य करने में असफल हो जाती है। दूसरी विफलता मोड II या मोड III विफलता किनारों के फाड़ने से संकेतित होती है जो केंद्र में शुरू होती है और फिर क्लैप किए गए किनारों के अंत तक जाती है। लोड में और वृद्धि ने मोड III की विफलता की शुरुआत की जिससे प्लेटों को तोड़ दिया गया। अंडेक्स के अधीन होने पर कठोर प्लेटों का व्यवहार भी समकक्ष फ्लैट प्लेट पर उनकी प्रभावकारिता की तुलना करने के लिए अध्ययन किया जाता है। जैसा कि अपेक्षित है, कठोर प्लेटें झुकने का विरोध करके अधिक कठोरता प्रदान करती हैं। चूंकि अधिकांश पानी के नीचे की संरचनाएं कठोर होती हैं, अध्ययन आमतौर पर संरचनात्मक विन्यास पाया जाता है। बराबर द्रव्यमान की समतुल्य ठोस प्लेट के सापेक्ष तुलना में कठोर प्लेटों को अंडेक्स लोड का सामना करने में अधिक प्रभावी पाया जाता है। विभिन्न भारों के लिए विरूपण प्रोफाइल भी पाए जाते हैं। यह भी पाया जाता है कि इस तरह की सरल संरचना की प्रतिक्रिया को संख्यात्मक

समीकरणों द्वारा उचित हद तक भी प्रदर्शित किया जा सकता है और यह एक ज्ञात अंडेक्स लोडिंग का सामना करने के लिए आवश्यक अधिकतम शक्ति को कम करने में मदद करेगा।

संख्यात्मक अध्ययन हनीकोम्ब सैंडविच संरचनाओं तक बढ़ाया जाता है जहां एक शहद कंघी कोर दो फ्लैट प्लेटों के बीच सैंडविच होता है, ऐसी संरचनाएं विस्फोट ऊर्जा को अवशोषित करने में उपयोग की जाती हैं और इस प्रकार संरचना को संरक्षित करती हैं। चेहरे की प्लेट विस्फोट भार से अवगत कराई जाती है और बैक प्लेट के कम विक्षेपण के संदर्भ में अर्जित लाभों का अध्ययन किया जाता है। बराबर द्रव्यमान की समतुल्य ठोस प्लेट के साथ तुलना की जाती है। विस्फोट भार का सामना करने के लिए एक ठोस प्लेट पर एक सैंडविच पैनल निर्माण के लाभ स्पष्ट रूप से निचले हिस्से की प्लेट विक्षेपण से स्पष्ट होते हैं, तुलनात्मक वजन ठोस प्लेट्स की तुलना में समान आवेग लोडिंग के अधीन होती है। प्रभाव या विस्फोट लोडिंग की प्रगति महत्वपूर्ण फ्रंट चेहरे झुकाव और प्रगतिशील सेल दीवार से पीछे की प्लेट के झुकाव और खींचने के लिए विस्फोट के स्रोत के निकट पैनल के केंद्र में बकलिंग से देखी जाती है। इसके अलावा, यह पाया गया कि झुकाव और खिंचाव विकृतियां सीमाबद्ध सीमाओं से केंद्र तक प्रगति करती हैं और आम तौर पर खींचने के लिए अंतिम आकार को प्रभावित करती हैं। सीमा की स्थिति में परिवर्तन वापस प्लेट विक्षेपण को बढ़ाने के लिए पाया जाता है लेकिन क्लैम्पड स्थितियों की तुलना में कोर क्रशिंग में कोई भूमिका नहीं है। सेल दीवार बकलिंग और कोर घनत्व में वृद्धि हुई क्योंकि आवेग बढ़ गया है। इसके अलावा, सैंडविच संरचनाओं के लाभ केवल बरकरार कोर के साथ स्पष्ट होते हैं और कोर क्रशिंग शुरू होने के कारण घटते रिटर्न होते हैं। इसलिए, समकक्ष ठोस प्लेटों पर लाभ प्राप्त करने के लिए उपयुक्त संयोजन पैनल की पहचान करना महत्वपूर्ण है। विभिन्न विभिन्न प्रकार के कोरों और उनकी पतन तंत्र में जांच से हमें विस्फोटक भार की रक्षा करने की दिशा में अधिक अंतर्दृष्टि मिल जाएगी।

संरचनाओं को अनुकूलित करने और उपयुक्त कॉन्फ़िगरेशन खोजने के लिए संरचनाओं के व्यवहार का आकलन जो संख्यात्मक विश्लेषण का उपयोग करके अंडेक्स लोड का सामना कर सकता है, पहले बताए गए प्रयोगात्मक माध्यमों की सीमा को कम करने के लिए एक अभिनव दृष्टिकोण है। संख्यात्मक विश्लेषण वाणिज्यिक रूप से उपलब्ध फेम पैकेज अबाकस का उपयोग कर किया जाता है।

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NOTATIONS

P_{\max}	:	Maximum pressure, MPa
W	:	Weight of explosive charge, kg
R	:	Standoff distance, m
R_o	:	Perpendicular shortest distance, m
θ	:	Decay constant, ms
I	:	Impulse load, kPa
E	:	Total energy, kJ/m^2
A_1, A_2, A_3, A_4		
K_1, K_2, K_3, K_4		Constants for different explosives
ρ	:	Density of water, kg/m^3
c	:	Speed of sound, m/s
TNT	:	Tri-nitro toluene explosive
ϵ_p	:	effective plastic strain
ϵ_p^*	:	normalized effective plastic strain rate
A, B, C, n & m	:	Johnson Cook material constants
ω	:	Damage parameter
ϵ^{pl}	:	Increment of the equivalent plastic strain
ϵ_f^{pl}	:	Strain at failure
u, v, w	:	Component displacements in xx, yy and zz directions
$\theta_x, \theta_y, \theta_z$:	Component rotations in xx, yy and zz directions
c_1	:	Characteristic length of shock wave in space